UNIVERSITY OF ALBERTA

Effects of Suspended Glacial Particles on the Bioavailability of Hydrophobic Organic Contaminants in Two Subalpine Lakes in the Canadian Rocky Mountains

by

Eric Braekevelt

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If we knew what it was we were doing, it would not be called research, would it?
Albert Einstein

Preface

The structure of this thesis follows the paper format outlined by the Faculty of Graduate Studies and Research, University of Alberta, 2000. The research is presented in three manuscripts, chapters 2 through 4. The introductory and concluding chapters are intended to outline the research, summarize the results and present areas of future research. Although I have made an effort to keep repetition to a minimum, common aspects that underlie the research are unavoidably repeated. Below is a list of manuscripts resulting from the three chapters as I expect them to be published.

Chapter 2. Braekevelt, E., D.C.G. Muir, D.W. Schindler and G. A. Stern. Effects of Suspended Glacial Particles on the Bioavailability of Hydrophobic Organic Contaminants in Two Subalpine Lakes in the Canadian Rocky Mountains.

Chapter 3. Braekevelt, E., D.C.G. Muir and D.W. Schindler. Sorption of Hydrophobic Organic Contaminants to Suspended Glacial Particles.

Chapter 4. Braekevelt, E., D.C.G. Muir and D.W. Schindler. Uptake and Elimination of Hydrophobic Organic Contaminants by *Hesperodiaptomus arcticus* (Crustacea: Copepoda) in the Presence of Suspended Glacial Particles.

Abstract

The objective of this study was to determine whether ingestion of suspended glacial particles is an important uptake route of hydrophobic organic contaminants (HOCs) by zooplankton in lakes of the Canadian Rocky Mountains. Both field data and laboratory experiments suggest that direct uptake of HOCs from water (bioconcentration) by zooplankton is a much more important uptake pathway than particle ingestion. HOC concentrations in zooplankton are related to their lipid content. Sorption of HOCs to glacial clays was quite low because of the low organic carbon content of the particles. Low concentrations of glacial clays do not appear to significantly hinder uptake by decreasing bioconcentration, or enhance it by particle ingestion. Particle ingestion also did not appear to affect HOC elimination rates. Transfer of HOCs from zooplankton to fish in glacier-fed lakes may depend primarily on lake turbidity: high visibility puts zooplankton and other invertebrates at risk of visual predation by fish.

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The Department of Biological Sciences not only provided a physical space for research, but also provided financial support by allowing me to teach during the school year. Brian Rolseth and others in the limnology laboratory were always willing to share equipment and laboratory space. Researchers within the department, especially Frank Wilhelm, Nat McMaster and Rolf Vinebrooke, fostered an atmosphere of cooperation and were always willing to discuss science (particularly statistics) and offer suggestions.

John Brzustowski, Toby Herman, Jeff Sleno, Frank Wilhelm and Jason Young assisted me during my field work. I thank them for their willingness to carry heavy loads, and for sharing in the beauty of the mountain parks. Ted Little from Earth and Atmospheric Sciences taught me more about particle size analysis than I ever wanted to know.

Special recognition must be given to Parks Canada and Banff National Park for providing permits and allowing this research to progress unhindered. I apologize to Charlie Pacas for not applying for those permits in person.

I am grateful for financial support from the Natural Sciences and Engineering Research Council of Canada (strategic grant to DWS) and the Canadian Circumpolar Institute (University of Alberta), and particularly grateful to Margaret Foxcroft for her adept management of finances and paperwork, which allowed me to conduct research with little bureaucratic interference.

I am particularly indebted to my parents, Janice and Charlie, who instilled in me the curiosity, independence and appreciation of excellence that led to my interest in science. This thesis is a testament to the atmosphere of support and scholarship they fostered.

Finally, I would like to thank Julie Guimond, for her support, patience, and dedication to our relationship despite both of our theses, and for teaching me statistics.

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1 Introduction

Hydrophobic organic contaminants (HOCs) include chlorinated hydrocarbons such as polychlorinated biphenyls (PCBs), toxaphene and DDT. HOCs are of concern because of their high persistence and chronic toxicity (Hoffmann 1996). Lake trout (*Salvelinus namaycush*) from Bow Lake have higher concentrations of HOCs than other lakes in the Canadian Rocky Mountains (Donald *et al.* 1993). These high concentrations are not due to biomagnification via an exceptionally long food chain: typically, HOC concentrations in zooplankton are much lower than in predatory fish (Kidd *et al.* 1995), but trout and zooplankton from Bow Lake have similar HOC concentrations (Campbell *et al.* 2000).

Some characteristics of Bow Lake make its biota particularly susceptible to contamination by HOCs. Organic chemicals evaporate from warm regions and are deposited in colder regions according to their volatility, in a process known as cold condensation (Wania & Mackay 1993). Chemicals of high volatility remain in the atmosphere, while less volatile chemicals condense or become associated with particles at lower temperatures and are deposited (Figure 1-1). The low average temperature of Bow Lake (due to its high elevation, ~2000 m above sea level) results in increased atmospheric deposition of HOCs by cold condensation (Blais *et al.* 1998), and the short ice-free season inhibits their evaporation (Swackhamer *et al.* 1988). Bow Lake is also oligotrophic, and organic contaminants are more bioavailable in lakes of low productivity (Larsson *et al.* 1992; Donald *et al.* 1998). Organisms in mountain lakes generally have larger lipid reserves, lower rates of growth and metabolism, and longer life spans than those in lakes of lower elevation (Wilhelm 1999). As a result, they accumulate HOCs

readily, are less able to dilute or eliminate them, and are exposed for a longer time (Larsson *et al.* 1991). In addition, glacial melt that flows into Bow Lake in the summer contains HOCs that were deposited on the glacier during the past several decades (Donald *et al.* 1999; Blais *et al.* 2001).

The meltwaters also supply large amounts of glacial clays to Bow Lake. Sorption of HOCs to these fine, largely inorganic particles can greatly affect their bioavailability and fate: chemicals that are freely dissolved are subject to diffusion-controlled processes such as volatilization and bioconcentration, while HOCs that are associated with particles are subject to advective processes such as settling and ingestion (Figure 1-2).

HOCs can be accumulated through bioconcentration, where freely dissolved chemical diffuses into the lipid compartments of the organism. Sorbing material in the water column hinders the bioconcentration of HOCs (Leversee *et al.* 1983; Eaton *et al.* 1983). However, HOCs can instead be accumulated by ingesting contaminated particles. *Hesperodiaptomus arcticus*, a large copepod found at relatively high densities in Bow Lake, ingests large amounts of glacial clays, as shown by gut contents (Campbell 1996) and the large proportion of fecal pellets in Bow Lake sediments (Smith & Syvitski 1982). High HOC concentrations in *H. arcticus* may be due to ingestion of glacial particles, and may provide a point of entry of HOCs into the Bow Lake food web.

The objective of this study was to determine whether HOC sorption to glacial particles increases uptake by zooplankton because of particle ingestion or reduces uptake by

decreasing the fraction of freely dissolved chemical, reducing bioconcentration. In the second chapter, HOC concentrations in zooplankton from two lakes that receive different glacial particle loads were compared. If HOC concentrations in zooplankton are due to bioconcentration, then concentrations should be lower in Peyto Lake, because the presence of suspended particles hinders bioconcentration of HOCs (Eaton *et al.* 1983) and Peyto Lake is more turbid than Bow Lake. On the other hand, if particle ingestion is an important means of HOC uptake, then zooplankton HOC concentrations should be greater in Peyto Lake than in Bow Lake.

Because only freely dissolved chemical can be bioconcentrated, it is necessary to develop analytical methods that can distinguish between sorbed and dissolved phases. Incomplete separation of bound and dissolved phases by conventional techniques such as filtration and centrifugation can overestimate the dissolved fraction. Sparging or stripping chemicals from solution with an inert gas has been used to determine Henry's law constants (Mackay *et al.* 1979), but it can also be used to measure sorption, because sorbed chemical is not subject to volatilization (Hassett & Milicic 1985). Sparging reduces many of the analytical artifacts associated with inadequate separation of phases. The third chapter examines the use of sparging in determining sorption coefficients, and compares this method to a conventional batch method.

Sorbed chemicals can be accumulated if they are ingested, but ingestion of uncontaminated material by invertebrates may increase HOC elimination rates (Landrum & Robbins 1990). If accumulation by ingestion is negligible, uptake experiments can be

used to estimate freely dissolved HOC concentrations, because the reduction in bioconcentration by sorption is proportional to the fraction of HOC sorbed. The fourth chapter examines the results of separate short-term uptake and elimination experiments, where zooplankton were exposed to radiolabeled HOCs in clear water and water containing sorbents. The objectives of the experiments were to examine whether HOC sorption to glacial particles increases uptake because of particle ingestion or reduces uptake by decreasing the fraction of freely dissolved chemical, reducing bioconcentration; to examine the effect of sediment ingestion on HOC elimination rates; and to evaluate the potential of uptake experiments to measure freely dissolved concentrations of HOCs in water.

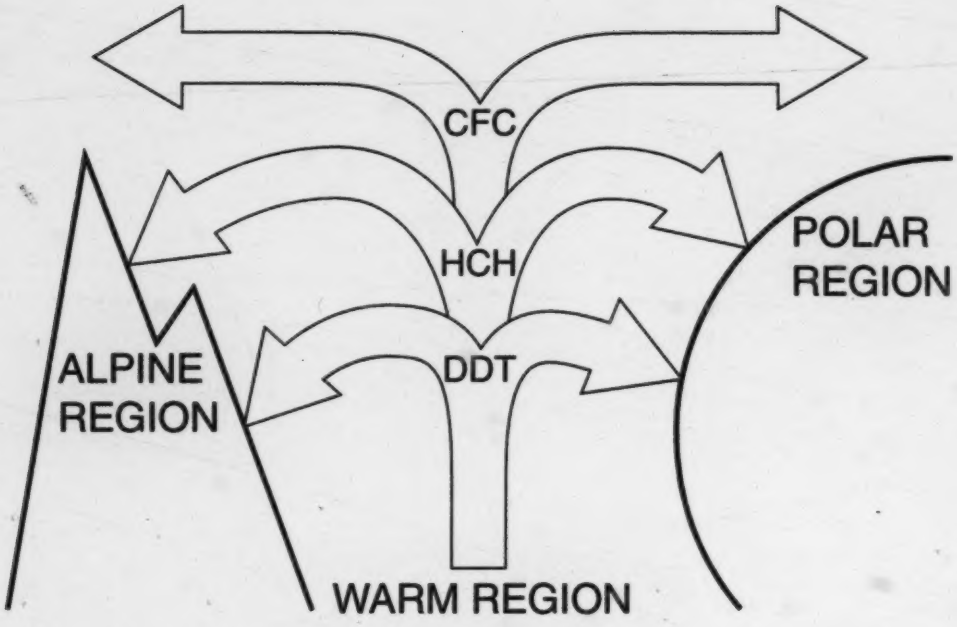
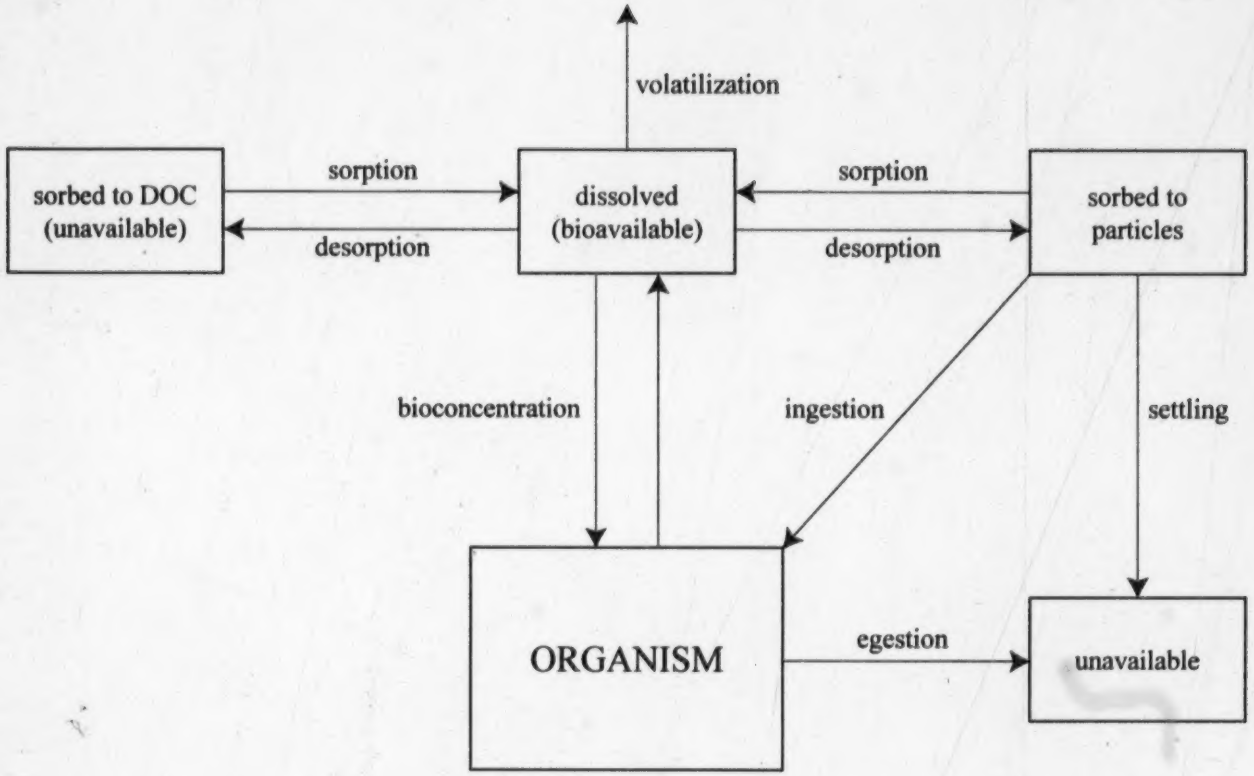


Figure 1-1. HOCs evaporate from warm regions and are deposited in colder regions according to their volatility, in a process known as cold condensation. Chemicals of high volatility, such as chlorofluorocarbons (CFC), remain in the atmosphere, while less volatile chemicals, such as the pesticides hexachlorocyclohexane (HCH) and dichlorodiphenyltrichloroethane (DDT), condense or become associated with particles at lower temperatures and are deposited.



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2 Effects of Suspended Glacial Particles on the Bioavailability of Hydrophobic Organic Contaminants in Two Subalpine Lakes in the Canadian Rocky Mountains

Introduction

Lake trout (*Salvelinus namaycush*) from subalpine Bow Lake have higher concentrations of hydrophobic organic contaminants (HOCs) such as chlorinated pesticides and polychlorinated biphenyls (PCBs) than other lakes in the Canadian Rocky Mountains (Donald *et al.* 1993). These high concentrations are not due to biomagnification via an exceptionally long food chain: typically, HOC concentrations in zooplankton are much lower than in predatory fish (Kidd *et al.* 1995), but trout and zooplankton from Bow Lake have similar HOC concentrations (Campbell *et al.* 2000).

Some characteristics of Bow Lake make its biota particularly susceptible to contamination by HOCs. The low average temperature of Bow Lake (due to its high elevation, ~2000 m above sea level) results in increased atmospheric deposition of HOCs (Blais *et al.* 1998), and the short ice-free season inhibits their evaporation (Swackhamer *et al.* 1988). Bow Lake is oligotrophic, and HOCs are more bioavailable in lakes of low productivity (Larsson *et al.* 1992; Donald *et al.* 1998). Organisms in mountain lakes generally have larger lipid reserves, lower rates of growth and metabolism, and longer life spans than those in lakes of lower elevation (Wilhelm 1999). As a result, they accumulate HOCs readily, are less able to dilute or eliminate them, and are exposed for a longer time (Larsson *et al.* 1991). In addition, glacial melt that flows into Bow Lake in

the summer contains HOCs that were deposited on the glacier during the past several decades (Donald *et al.* 1999; Blais *et al.* 2001).

HOCs may be accumulated through bioconcentration, where freely dissolved chemical diffuses into the lipid compartments of the organism. Sorbing material in the water column hinders the bioconcentration of HOCs (Leversee *et al.* 1983; Eaton *et al.* 1983), but the chemicals may instead be accumulated by ingesting the HOC-contaminated particles. The glacial meltwaters supply large amounts of fine particulate matter to Bow Lake. *Hesperodiaptomus arcticus*, a large copepod found at relatively high densities in Bow Lake, ingests large amounts of these glacial clays, as shown by gut contents (Campbell 1996) and the large proportion of fecal pellets in Bow Lake sediments (Smith & Syvitski 1982). High HOC concentrations in *H. arcticus* may be due to ingestion of glacial particles, and may provide a point of entry of HOCs into the Bow Lake food web.

The objective of this study was to examine the importance of glacial particle ingestion on HOC concentrations in zooplankton. HOC concentrations in zooplankton from two lakes that receive different glacial particle loads were compared. If particle ingestion is an important means of HOC uptake, then zooplankton HOC concentrations should be greater in Peyto Lake, which receives more glacial clays than Bow Lake. Semipermeable membrane devices (SPMDs) were also deployed in each lake to elucidate possible differences in HOC sources and bioavailability between the lakes.

SPMDs are lengths of semipermeable tubing (such as polyethylene) containing an organic solvent or nonpolar lipid. When placed in an aquatic environment, HOCs diffuse through the semipermeable membrane and partition into the solvent. Only freely dissolved chemical is accumulated, because the membrane excludes particles and most dissolved organic matter. If a chemical is at equilibrium between the lipid and aqueous phases, the large database of published octanol-water partition coefficients (K_{OW}) can be used to estimate its concentration in water, because the lipid-water partition coefficient K_{LW} of a chemical is approximately equal to its K_{OW} (Chiou 1985).

Triolein (1,2,3-tri[cis-9-octadecenoyl]glycerol), a triglyceride of oleic acid, has traditionally been used in SPMDs. Contrary to statements by Huckins *et al.* (1990; 1996), triolein itself is found in very low concentrations in animal fats. While it is true that oleic acid is usually the dominant fatty acid in neutral fish lipids (Henderson & Tocher 1987), triglycerides with three identical fatty acids are rare, consisting instead of a mixture of fatty acids (Hilditch & Williams 1964). Sweet almond oil is a fairly consistent mixture of triglycerides of oleic (18:1, ~75%), linoleic (18:2, ~20%) and saturated (18:0, ~5%) acids, and unlike triolein, has a melting point near that of fish oils (Eckey 1954; Kirschenbauer 1960). Blanks and accumulation of HOCs in SPMDs containing triolein were compared to those containing much cheaper almond oil.

Methods

Study Area

Bow Lake and Peyto Lake are both subalpine, glacier-fed lakes in Banff National Park, Canada, near the Alberta-British Columbia border (Figure 2-1). Both lakes are fed by the Wapta Icefield. Peyto Lake receives more of its water from glacial inputs, and the suspended particle load of incoming streams is much higher than in Bow Lake, where a small lake at the foot of Bow Glacier acts as a sediment trap (Smith 1981). Peyto Lake is therefore more turbid, poorly thermally stratified and less variable in surface temperature in the summer (Table 2-1). The zooplankton communities in both lakes are dominated by calanoid copepods, *Hesperodiaptomus arcticus* in Bow Lake and *Diaptomus tyrelli* in Peyto Lake. Fish species in Bow Lake are lake trout (*Salvelinus namaycush*) and mountain whitefish (*Prosopium williamsoni*), while Peyto Lake contains only cutthroat trout (*Oncorhynchus clarki*).

Semipermeable Membrane Devices (SPMDs)

Three pairs of SPMDs were deployed in each lake. They consisted of a 70 cm length of 5.7 cm wide 50 μm thick lay-flat polyethylene tubing (total mass of tubing = 4.4 g), heat sealed at both ends, filled with 1.0 mL of lipid. Both the triolein and sweet almond oil were obtained from Sigma Chemical Co. and were used as received. The tubing was cleaned by Soxhlet extraction for 12 h each in acetone and dichloromethane (DCM). The SPMDs were stored at –50 °C in clean glass jars with foil-lined lids until use, and a blank was exposed to air during assembly and field deployment. The SPMDs were suspended

in metal cages at a depth of 2 m for periods of 20 d or 50 d. A thermistor (Hobo-temp, Hoskin Scientific) was attached to the cage to monitor temperature.

After deployment, SPMDs were placed in clean glass jars with foil-lined lids and refrigerated for transport to the laboratory, where they were stored at –50 °C until extraction. The SPMDs were allowed to thaw, and biofilm was wiped from the SPMD surface with paper towels. Extra polyethylene tubing was cut off, and the SPMDs were dialyzed twice in 125 mL of hexane for 24 h. A procedural blank was run with every sample group, and was extracted in the same manner as the field-deployed SPMDs. Recovery standards (100 ng each of PCB 30 and octachloronaphthalene) were added at the dialysis step. The hexane fractions were combined, evaporated, and dried over anhydrous sodium sulfate (baked at 600 °C for 6 h).

Water

A solid-phase extraction (SPE) system was used in this study to allow the collection and extraction of large water volumes without transporting large amounts of equipment or water. Polyurethane foam (PUF) plugs (15 cm long and 9 cm in diameter, 0.05 g cm^{-3} density, 21 g total mass) were cleaned before use by soaking them in 1 M NaOH to disrupt bonding of HOCs (Maguire & Tkacz 1989). They were then rinsed well with deionized water, then Soxhlet extracted for 24 h each with acetone, DCM and methanol, and stored in methanol. A single PUF plug was packed into a stainless steel column (14 cm long, 7.3 cm ID), conditioned with HPLC grade water, and spiked with the recovery standards before use. Glass-fibre filters (Gelman GF/F, 142 mm diameter, 1 μm nominal pore size) used in the filter unit were baked overnight at 500 °C.

Ninety litres of water were extracted on-site. The SPE system consisted of a small cylinder of compressed nitrogen, an 18-L airtight stainless steel vessel, a filter unit (142 mm stainless steel Millipore), a needle valve for flow rate control, and the PUF column, connected in series by ¼" ID PTFE tubing (Figure 2-2). Recovery standards were not added to the water before extraction. Water was forced from the vessel through the filter unit and PUF by pressure from the compressed gas. After field deployment, PUFs were extracted in the column with 500 mL of acetone, followed by 500 mL of hexane. The acetone fraction was back-extracted twice with 100 mL of hexane. The hexane fractions were then combined, evaporated to 3 mL, and dried over anhydrous sodium sulfate. Procedural blanks were run with every sample group, and consisted of cleaned PUF plugs in columns. They were prepared and extracted in the same manner as the field-deployed SPE columns.

Zooplankton

Zooplankton were collected by 10 m vertical tows with an 80 cm diameter plankton net (64 μm mesh), because the highest densities of *H. arcticus* are found in the top 10 m of the water column (Donald *et al.* 1994). Collected samples were preserved with formalin solution due to difficulties with keeping samples sufficiently cold in the field. Formaldehyde has a log K_{OW} of –1, so lipids and nonpolar compounds presumably did not readily leach into the formalin solution. The formalin solution containing each sample of zooplankton was extracted and analyzed separately to determine if leaching of HOCs occurred. HOCs in the formalin extracts were very low, so it was assumed that little leaching occurred.

Zooplankton were freeze-dried, then extracted using a ball mill (Grussendorf *et al.* 1970; Muir *et al.* 1990). Approximately 2 g of freeze-dried zooplankton (accurately weighed) and 10 g anhydrous sodium sulfate were spiked with the recovery standards and extracted twice with 25 mL of hexane. A fraction of the extract was evaporated to dryness for gravimetric lipid determination, and those extracts containing over 100 mg of lipid were subjected to gel permeation chromatography. Extracts were evaporated to 1 mL in preparation for column cleanup. A procedural blank consisting of anhydrous sodium sulfate was freeze-dried and extracted with every sample group.

Sediments

A sediment core from Bow Lake was taken in the winter of 1998 with a 2 m × 10 cm ID percussion corer. The core was cut into 1-cm sections and each section was freeze-dried. ^{137}Cs activity in dried sediments was measured using a gamma counter (Robbins & Edgington 1975). Sections were roughly dated by assuming that peak ^{137}Cs activity corresponds to 1963, when nuclear weapons testing was highest. Percent loss on ignition (%LOI) was determined by weight difference before and after combustion of dried sediments overnight at 500 °C, and converted to percent organic carbon (%OC) using an empirical relationship developed by Håkansson and Jansson (1983):

$$\%OC = 0.48 \times (\%LOI) - 0.73 \qquad (2\text{-}1)$$

Sediments were extracted on a Dionex ASE 200 accelerated solvent extractor. Approximately 5 g of freeze-dried sediment was placed in a 33-mL stainless steel ASE cell and spiked with the recovery standards. The remaining dead volume of the cell was

filled with anhydrous sodium sulfate. The cells were then placed in the ASE and extracted with DCM at a temperature of 100 °C and a pressure of 13.8 MPa. After a 5 min thermal equilibration time, the extraction cell was filled with solvent, extracted under static conditions for 10 min, then rinsed with ~30 mL of solvent. This cycle was then repeated. The cell was then purged with high-purity nitrogen for 100 s (Tomy & Stern 1999). Extracts were dried over anhydrous sodium sulfate and evaporated to 1 mL.

Sample Cleanup and Analysis

Extracts were treated with activated copper powder to remove elemental sulfur. Florisil was baked at 600 °C for 6 h and 1.2% deactivated with water before use. Eight grams of Florisil was slurry-packed with hexane into a 1 cm ID × 30 cm glass column equipped with a Teflon stopcock, and topped with 1 cm of anhydrous sodium sulfate. The 1 mL sample was added to the top of the column and three fractions were collected. The first fraction (F1) was eluted with hexane, and contained PCBs, *p,p'*-DDE, chlorobenzenes, chlorostyrenes, mirex and some toxaphene and chlordane components. The second fraction (F2), was eluted with 15% DCM in hexane, and contained hexachlorocyclohexanes (HCHs) and most toxaphene, chlordane and dichlorodiphenyltrichloroethane (DDT) components. The third faction (F3), containing dieldrin, endrin and heptachlor epoxide, was eluted with 50% DCM in hexane. Elution volumes were adjusted to recover >95% of *p,p'*-DDE and <5% of *p,p'*-DDT in F1, and <5% of heptachlor epoxide in F3 (Norstrom *et al.* 1988). After cleanup, 50 ng of aldrin was added to each fraction as an internal standard. Fractions were then evaporated to 200 µL and analyzed by high-resolution gas chromatography with electron capture detection (HRGC-ECD) on a Varian 3600 gas chromatograph.

A 60 m DB-5 capillary column (0.32 mm ID, 0.25 μm film thickness, J&W Scientific) was used, with the hydrogen carrier gas maintained at a flow rate of 1.0 mL min^{-1} with an Alltech EPC 1000 injector pressure programmer. One-microlitre injections were performed with an autosampler. The injector temperature was 220 °C, the detector 300 °C, and the oven temperature program was 100 °C (2 min), ramped to 150 °C at 15 °C min^{-1}, ramped to 265 °C at 2 °C min^{-1}, and held for 15 min. The following chemical groups were quantified: PCBs, HCHs, DDT isomers, chlorobenzenes, cyclodiene components (including chlordanes, nonachlors, heptachlor and heptachlor epoxide, aldrin, dieldrin, endrin, mirex and photomirex), and toxaphene. All HOCs except toxaphene were quantified by comparing chemical peak areas (identified by retention time) to those of commercially available standards of known concentration. Toxaphene was quantified by comparing known toxaphene peaks to the total area of all peaks in a technical toxaphene standard of known concentration. Concentrations in water, SPMDs and zooplankton were blank-corrected by subtracting the procedural blank value from the same sample group, while sediments were blank-corrected by subtracting a deep core slice (140 cm). Accumulation factors (AF, the ratio of chemical concentration in lipid to its concentration in water) were calculated for zooplankton and SPMDs from average lipid and water concentrations.

Results and Discussion

HOC Concentrations in Environmental Media

In general, concentrations of HOCs in water, sediments and zooplankton were much lower than those in lakes close to industrial activity, such as the Great Lakes (Oliver & Niimi 1988; Haffner *et al.* 1994), but were comparable to those of remote lakes (Macdonald & Metcalfe 1991; Muir *et al.* 1995).

HOC concentrations in zooplankton were 2-3 times higher in Peyto Lake (Tables 2-2 and 2-3), but the zooplankton were also significantly higher in lipid. When expressed on a lipid weight basis, HOC concentrations in zooplankton from the two lakes were approximately equal, suggesting that lipid content is an important determinant of HOC body burden.

Wet-weight HOC concentrations in zooplankton from the two study lakes compare well with those from other remote regions (Kawano *et al.* 1988; Macdonald & Metcalfe 1991; Muir *et al.* 1992; Kucklick *et al.* 1996; Paterson *et al.* 1998). However, when expressed on a lipid weight basis, concentrations in zooplankton from the other lakes were much higher (Macdonald & Metcalfe 1991; Paterson *et al.* 1998), possibly due to the much lower lipid content of zooplankton in these lakes. In systems of low organic carbon, sorption has been observed to be much higher than would be predicted on the basis of organic carbon alone (Schwarzenbach & Westall 1981; Piwoni & Banerjee 1989; Rebhun *et al.* 1992), suggesting that sorption to phases other than organic carbon are important.

Similarly, organic phases other than lipid may become more important in accumulating HOCs as the lipid content of the organism decreases.

There were no differences in the degree of biofouling between triolein and almond oil SPMDs, and blanks were approximately equal for all HOCs examined (Table 2-4). With the exception of the PCBs, almond oil and triolein SPMDs accumulated similar amounts of HOCs (Table 2-5).

HOC concentrations in water compared favourably with those of other studies of Bow Lake (Campbell 1997; Blais *et al.* 2001), with the exception of γ-HCH, which was lower by a factor of 2-3. HCHs were approximately an order of magnitude lower than another study of western Canadian surface waters (Crosley *et al.* 1998). This disparity may be due to differences in analytical methods. SPE methods have been shown to extract only freely dissolved compounds (Bedford 1974; Landrum *et al.* 1984), while the liquid-liquid extraction methods used in the other studies may co-extract HOCs sorbed to particles and dissolved organic matter, resulting in an overestimation of HOC concentrations in water. However, HCHs are relatively polar HOCs, and do not sorb significantly: co-extraction of sorbed HCHs would probably not significantly increase their apparent aqueous concentration. Differences may instead be due to poor extraction efficiency of HOCs from the water as it was pumped through the PUF plug. Although recoveries from PUF plugs averaged about 70%, these reflect the extraction efficiency of HOCs from the PUF itself rather than the ability of PUF to remove the analytes from water. Decreased

extraction efficiency may have been due to the low temperature of the water (Saxena *et al.* 1977).

Bow Lake sediments were very low in HOCs (Table 2-2, Figure 2-3), suggesting that the ability of glacial particles to sorb HOCs and remove them from the water column is very low. The organic carbon content of the sediments was 1.3% at the surface and decreased with depth to a minimum of 0.3%. Sediment HOC concentrations and organic carbon content were similar to arctic lakes (Mudroch *et al.* 1992; Muir *et al.* 1995; Muir *et al.* 1996). PCBs were the most abundant HOCs, with an average total concentration of 6 ng g^{-1} (dry weight), and were dominated by the trichlorobiphenyl congeners 31/28 (IUPAC numbering system). Lakes that receive PCBs from atmospheric deposition have a higher proportion of such lower chlorinated congeners than point-source contaminated lakes (Macdonald & Metcalfe 1991; Muir *et al.* 1996).

Peak HOC concentrations in Bow Lake sediments occurred at a depth of 4-5 cm, which corresponds to the mid-1960's, when HOC usage was highest (Figure 2-3). PCBs show an additional maximum at 10-11 cm, which corresponds to the late 1940's. Sediments at this depth had a higher proportion of hexa- and heptachlorobiphenyls than other sediment slices, suggesting contamination from a local source, such as the lodge at the edge of the lake, or the highway that passes through the watershed.

Accumulation Factors (AFs)

There were no consistent differences in zooplankton and SPMD AFs between the two lakes (Table 2-6). Differences in AFs between the two lakes were greatest for the PCBs,

probably due to difficulties in the analysis of the aqueous phase (discussed below). With the exception of the PCBs, AFs for the two lakes were usually within 0.2 log units. This suggests that direct uptake from water (i.e. bioconcentration) rather than particle ingestion is the dominant uptake route of HOCs by zooplankton. Ingestion of suspended glacial particles by zooplankton in the much more turbid Peyto Lake does not result in increased HOC uptake, and the ability of glacial particles to sorb HOCs and reduce uptake by bioconcentration is very low.

For relatively polar compounds such as the HCHs, SPMDs exposed for 20 d yielded AFs similar to those exposed for 50 d, suggesting that equilibrium was reached. For more hydrophobic compounds, however, 20-d SPMD AFs were lower than 50-d AFs, and both 20-d and 50-d AFs were lower than the chemical K_{OW}, suggesting that the SPMDs had not yet reached equilibrium, even after 50 d. Zooplankton were assumed to have reached equilibrium due to their high surface area to volume ratio and long exposure time.

The relationship of zooplankton log AFs to log K_{OW} was curvilinear (Figure 2-4), with peak HOC accumulation occurring at a log K_{OW} of about six. This has been observed elsewhere (Oliver 1984; Meylan *et al.* 1999). Decreased accumulation of extremely hydrophobic HOCs (log K_{OW} >6) may be due to steric hindrances to membrane permeation (Opperhuizen *et al.* 1985), low chemical bioavailability as a result of sorption to particles (Gobas & Mackay 1987), or dilution by rapid organism growth (Swackhamer & Skoglund 1993). The PCBs were the most hydrophobic chemicals examined, and

difficulties with their analysis in water (discussed below) may also have contributed to the non-linear relationship.

With the exception of the PCBs, zooplankton AFs were consistently higher than octanol-water partition coefficients (Table 2-6), suggesting that organic carbon pools other than lipid can store HOCs (Swackhamer & Skoglund 1993), or that octanol is not a perfect surrogate for lipid (Barron 1990). It has been suggested that phytoplankton AFs be normalized to organic carbon rather than lipid content (Karickhoff 1984; Skoglund & Swackhamer 1999).

Analytical Problems

A solid-phase extraction (SPE) system was used in this study to allow the collection and extraction of large water volumes without transporting large amounts of equipment or water. Polyurethane foam (PUF) has been used as a solid-phase sorbent to sample both air (Swackhamer *et al.* 1988; McConnell *et al.* 1996) and water (Bowen 1970; Bergen *et al.* 1993; Götz *et al.* 1994; Axelman *et al.* 1997). In the glacial study lakes, high suspended solids concentrations were expected, and PUF appeared the most suitable SPE sorbent because its highly porous structure provides a high surface area for chemical absorption while being less subject to clogging. Commercial SPE products such as Empore disks and Sep-Pak C_{18} columns are subject to clogging because they have very small pores. Packed columns like XAD can compress during use, making flow control difficult and increasing the likelihood of clogging.

However, the cleaning of PUF was problematic. Extracts often contained interferences that obscured some HOC peaks during chromatography, and contamination by PCBs was a problem. All blanks contained measurable concentrations of PCBs (Table 2-5). One PUF sample group was particularly high in both PCBs and DDT and was not included. All samples, including sediments, zooplankton, SPE sorbents and SPMDs are susceptible to airborne contamination if exposed to laboratory air (Alcock *et al.* 1994). SPMDs and PUF are extremely effective at absorbing chemicals from air, and both have been used to measure concentrations of airborne contaminants (Petty *et al.* 1993; McConnell *et al.* 1996). PCBs leak from older electrical devices such as transformers, capacitors and fluorescent light ballasts (MacLeod 1981; Weistrand *et al.* 1992), and from caulking and elastic sealants (Balfanz *et al.* 1993). High concentrations of PCBs in indoor air are often found in buildings built before PCBs were banned in 1977 (MacLeod 1981; Wallace *et al.* 1996). SPMDs and PUF plugs were cleaned, assembled and extracted in a building built in 1955, suggesting that the samples were contaminated by high indoor air concentrations of PCBs due to the age of the building.

There were also difficulties with the analysis of SPMDs. There was a white precipitate of unknown origin in F1 in almost all the SPMD extracts. The precipitate did not seem to adversely affect chromatography. However, chromatograms of F3 were difficult to interpret, and many compounds eluting in this fraction were unable to be quantified (Tables 2-3 and 2-4). The interferences were likely due to the presence of lipid. The Florisil cleanup column can only handle about 100 mg of lipid, and lipids usually elute in F3 if the column is overloaded (personal communication, N. P. Grift, Freshwater

Institute, Department of Fisheries and Oceans, Winnipeg, Canada). To overload the cleanup columns, lipid carryover during dialysis must have been greater than ~10%. This suggests that some of the SPMDs may have been punctured during deployment, because the average lipid carryover of SPMDs tested separately was 6.3 ± 0.3%.

Analytical problems associated with the removal of lipids have led some to question whether triolein is even necessary, particularly when the polyethylene membrane itself accumulates significant quantities of pollutants (Hofelt & Shea 1997). The amount of analyte in the membrane can be as much as 50% of the total (Huckins *et al.* 1996). The presence of triolein in SPMDs has been shown to make little difference in the uptake of HOCs of K_{OW} >6, although lipid is a convenient carrier for a reference compound, and empty SPMDs are more subject to biofouling (Booij *et al.* 1998).

Alternatively, a hydrophobic organic solvent can be used in SPMDs. There are no problems associated with lipid removal. The SPMDs can be cut open and the solvent physically removed rather than dialyzed, reducing interferences from polyethylene additives and biogenic material on the SPMD surface. Unfortunately, the high membrane permeability of relatively low molecular weight solvents may result in their loss by diffusion into the surrounding water, and uptake may be inhibited because HOCs must diffuse against the outward solvent flux (Huckins *et al.* 1990). However, Södergren (1987) observed only an 8% loss of hexane after a full year of exposure, and larger quantities of solvents than the much more expensive triolein can be used in SPMDs, which can then be concentrated to compensate for any losses. Hexane-filled dialysis bags

also appear to be much less susceptible to biofouling, presumably because hexane impregnates the membrane and inhibits growth due to its toxicity (Södergren 1987; Johnson 1991). Measures to prevent biofouling of triolein-filled SPMDs, such as weekly rinsing with a biocide, are ineffective and labor intensive (Ellis *et al.* 1995). SPMDs in both Bow and Peyto Lakes were highly biofouled, despite significant light attenuation from high lake turbidity.

If a chemical of known hydrophobicity is at equilibrium between the lipid and aqueous phases, its concentration in water can be estimated. However, HOCs generally approach equilibrium very slowly, and the time required to reach equilibrium increases with chemical hydrophobicity (Hawker & Connell 1985). The non-achievement of equilibrium in the SPMDs precluded the estimation of HOC concentrations in water.

Aqueous HOC concentrations can also be estimated from SPMD uptake rates, which can be determined from kinetic uptake data, or by measuring the dissipation of chemical from a spiked SPMD into clean flowing water (Huckins *et al.* 1993). Rates of HOC uptake are assumed to be limited by the polyethylene membrane, and therefore system-independent (Huckins *et al.* 1990; Huckins *et al.* 1993). However, SPMD uptake rates have been shown to be affected by water flow (Booij *et al.* 1998), suggesting that uptake may be limited by the aqueous diffusion layer, particularly for more hydrophobic chemicals (Gobas & Mackay 1987; Gale 1998). In addition, membrane permeability increases with temperature (Huckins *et al.* 1993), while membrane biofouling tends to decrease uptake rates (Ellis *et al.* 1995). Unless SPMDs are allowed to reach equilibrium with the water,

using them to estimate aqueous HOC concentrations is problematic, due to the difficulty in obtaining accurate uptake and release rates (Booij *et al.* 1998).

Huckins *et al.* (Huckins *et al.* 1993) suggested using a permeability reference standard (a chemical of moderate SPMD fugacity added to the solvent before SPMD deployment) to correct SPMD uptake rates for environmental variables. The release kinetics of such a standard could be measured by using a radiolabeled compound, which could be non-destructively sampled during SPMD deployment. Housing the SPMD in a length of pipe, with a pump at one end and a flowmeter at the other would control the flow of water around the SPMD, which would allow a more accurate estimation of uptake rates. However, it would also increase the complexity, expense and probability of failure of the device.

Despite such analytical problems, SPMDs offer a number of advantages over traditional water sampling, including the integration of HOC concentrations over a long exposure time, and the concentration of chemicals to allow easier detection. Rather than use SPMDs to estimate water concentrations, they could be used to correct for differences in HOC concentrations and bioavailability among water bodies. AFs are also used to compare water bodies with varying contaminant exposure, by normalizing HOC concentrations in biota to the concentration in water. However, AFs can be highly variable due to the problems associated with the analysis of extremely hydrophobic chemicals in water. The ratio of concentrations in lipid and SPMD phases could be used

as an alternative to AFs, eliminating the need for the collection of large water volumes and its subsequent troublesome analysis.

In summary, low concentrations of glacial clays do not appear to significantly hinder uptake by decreasing bioconcentration, or enhance it by particle ingestion. Higher HOC concentrations in predatory fish from Bow Lake than those from other glacier-fed lakes may instead be due to indirect effects of glacial particles on food web dynamics. Glacial particles increase lake turbidity, which can affect visual predator-prey relationships. Bow Lake receives a significant input of HOCs from the glacial stream without receiving large amounts of glacial particles because the lake at the foot of Bow Glacier acts as a sediment trap. The abundant filter-feeding zooplankton ingest the remaining glacial particles and form them into fecal pellets. The pellets settle out of the water column much faster than uningested material, resulting in rapid lake clarification (Smith & Syvitski 1982; Gliwicz 1986), and putting zooplankton and other invertebrates at risk of visual predation by fish.

Although stomach content data indicate that Bow Lake trout feed primarily on benthic invertebrates, with *H. arcticus* comprising less than 10% of the diet (Donald *et al.* 1994; Campbell *et al.* 2000), stomach contents were collected only in the summer. Stable carbon isotopes, which integrate long-term dietary patterns, indicate that much of the lake trout diet is pelagic (Campbell *et al.* 2000). *H. arcticus* is the only pelagic organism that is likely prey for lake trout, and is probably ingested by trout primarily in the winter. Concentrations of HOCs in zooplankton tend to be highest in winter, when lipid content is high and aqueous HOC concentrations are high due to reduced volatilization from ice-

covered lake surfaces (Hargrave *et al.* 2000). Lake trout may therefore ingest significant quantities of HOCs during the winter.

Conclusions

Direct uptake of HOCs from water (bioconcentration) by zooplankton appears to be a much more important uptake pathway than ingestion of HOCs sorbed to glacial particles. HOC concentrations in zooplankton are related to their lipid content. Suspended glacial particles do not appear to significantly hinder uptake by decreasing bioconcentration, or enhance it by particle ingestion. Higher HOC concentrations in predatory fish from Bow Lake than in other glacier-fed lakes may be due to its lower turbidity, which put zooplankton and other invertebrates at risk of visual predation by fish.

Almond oil SPMDs are a comparable and much cheaper alternative to triolein SPMDs. Despite some problems, SPMDs offer a number of advantages over traditional water sampling, and could be used to correct for differences in HOC concentrations and bioavailability among water bodies, similar to AFs.

Table 2-1. Physical and chemical characteristics of two glacier-fed lakes in Banff National Park.

	Bow Lake	Peyto Lake
Maximum depth (m)	51	49
Mean depth (m)	22.9	27.8
Elevation (m above sea level)	1940	1844
Area (km^2)	2.8	1.4
Average surface temperature (°C, summer 1999)	6.1 - 11.5	7.7 - 7.9
Average glacial stream discharge (Smith *et al.* 1982) ($m^3 h^{-1}$, summer 1975)	156	360
Secchi depth (m, July 1999)	4.0	1.0
Dissolved organic carbon (mg L^{-1}, summer 1999)	0.66 ± 0.12	0.52 ± 0.09
Zooplankton density (individuals m^{-3}, summer 1999)	3000 ± 1800	800 ± 430

Table 2-2. Average HOC concentrations in Bow Lake water, zooplankton and sediments (blank corrected, mean ± 1 SD).

	Water (n = 3)	Zooplankton (n = 4)		Sediments (4-5 cm depth)	
	(pg L^{-1})	(ng g^{-1}, dry weight)	(ng g^{-1}, lipid weight)	(ng g^{-1}, dry weight)	(ng g^{-1} organic carbon)
Polychlorinated biphenyls (PCBs)					
PCB 31/28	5.0 ± 1.6	0.42 ± 0.40	4.7 ± 2.9	0.68	68
PCB 52	obs[a]	0.22 ± 0.26	2.0 ± 2.3	0.41	41
PCB 49	7.7 ± 13	0.14 ± 0.20	1.3 ± 1.7	0.26	26
PCB 70/76	7.3 ± 7.5	0.22 ± 0.05	2.8 ± 0.6	0.21	21
PCB 66/95	8.8 ± 9.5	0.44 ± 0.17	6.1 ± 3.3	0.38	38
PCB 101/89	4.7 ± 7.3	0.31 ± 0.18	3.8 ± 1.9	0.13	13
PCB 110	7.0 ± 12	0.009 ± 0.013	0.077 ± 0.11	0.047	4.7
PCB 149	5.2 ± 9.0	0.42 ± 0.33	4.9 ± 3.4	0.14	14
PCB 118	16 ± 28	0.52 ± 0.41	5.6 ± 3.8	0.14	14
PCB 153	14 ± 24	0.34 ± 0.29	5.7 ± 7.3	0.088	8.8
PCB 138	21 ± 36	0.14 ± 0.12	1.7 ± 1.4	0.075	7.5
PCB 180	< 0.2	0.23 ± 0.14	3.8 ± 4.1	0.021	2.1
Total	200 ± 200	7.4 ± 2.6	97 ± 46	4.4	440
Hexachlorocyclohexanes (HCHs)					
α-HCH	120 ± 9	0.48 ± 0.39	5.0 ± 2.7	0.066	6.6
γ-HCH	94 ± 12	0.47 ± 0.32	5.1 ± 1.7	0.053	5.3
Chlorobenzenes					
Pentachlorobenzene	1.5 ± 1.5	0.31 ± 0.12	3.8 ± 1.1	0.17	17
Hexachlorobenzene	8.7 ± 1.9	1.4 ± 0.70	16 ± 2.5	0.25	25

[a]obs: obscured by an analytical interference.

Table 2-2 (continued). Average HOC concentrations in Bow Lake water, zooplankton and sediments (blank corrected, mean ± 1 SD).

	Water (n = 3)	Zooplankton (n = 4)		Sediments (4-5 cm depth)	
	(pg L^{-1})	(ng g^{-1}, dry weight)	(ng g^{-1}, lipid weight)	(ng g^{-1}, dry weight)	(ng g^{-1} organic carbon)
DDT isomers					
p,p'-DDE	16 ± 5.6	5.6 ± 1.5	81 ± 56	2.0	200
o,p'-DDE	0.76 ± 0.95	0.48 ± 0.10	6.4 ± 2.6	0.17	17
p,p'-DDT	6.3 ± 2.3	5.7 ± 1.5	81 ± 48	2.0	200
o,p'-DDT	1.6 ± 2.4	2.0 ± 0.46	28 ± 13	0.19	19
p,p'-DDD	5.5 ± 1.0	3.7 ± 0.97	49 ± 15	0.49	49
o.p'-DDD	2.0 ± 3.5	0.93 ± 0.31	12 ± 2.4	< 0.004	< 0.4
Cyclodienes					
cis-Chlordane	1.9 ± 0.3	1.8 ± 0.68	23 ± 4.3	0.024	2.4
trans-Chlordane	0.60 ± 0.70	1.0 ± 0.47	12 ± 2.4	< 0.003	< 0.3
cis-Nonachlor	1.9 ± 0.3	1.5 ± 0.6	19 ± 5	< 0.003	< 0.3
trans-Nonachlor	2.6 ± 1.1	2.6 ± 0.81	33 ± 11	0.019	1.9
Oxychlordane	0.10 ± 0.16	0.19 ± 0.20	1.7 ± 1.7	< 0.003	< 0.3
Heptachlor epoxide	16 ± 0.3	0.78 ± 0.31	9.4 ± 0.7	0.042	4.2
α-Endosulfan	24 ± 12	1.1 ± 0.27	14 ± 4.1	0.032	3.2
Dieldrin	19 ± 0.4	1.8 ± 0.70	21 ± 2.6	0.067	6.7
Endrin	7.6 ± 1.0	0.52 ± 0.09	6.8 ± 2.0	< 0.003	< 0.3
Toxaphene					
T2 (B8-1413)	8.5 ± 5.3	2.4 ± 0.72	30 ± 8.1	0.007	0.69
T12 (B9-1679)	29 ± 9	5.2 ± 1.4	68 ± 26	0.004	0.41

Table 2-3. HOC concentrations in Peyto Lake water, SPMDs and zooplankton (blank corrected, mean ± 1 SD).

	Water (n = 3) (pg L^{-1})	Triolein SPMDs (ng g^{-1}, lipid weight)		Zooplankton (n = 4)	
		20-d (n = 5)	50-d (n = 2)	(ng g^{-1}, dry weight)	(ng g^{-1}, lipid weight)
Polychlorinated biphenyls (PCBs)					
PCB 31/28	11 ± 12	0.27 ± 0.24	< 0.1	0.63 ± 0.34	2.4 ± 1.8
PCB 52	obs[a]	0.054 ± 0.050	< 0.1	0.63 ± 0.20	2.3 ± 1.2
PCB 49	5.5 ± 9.5	0.17 ± 0.02	< 0.1	0.76 ± 0.35	2.7 ± 1.3
PCB 70/76	5.0 ± 8.6	0.064 ± 0.084	0.027 ± 0.038	0.45 ± 0.16	1.6 ± 0.4
PCB 66/95	4.9 ± 8.5	0.22 ± 0.21	0.090 ± 0.062	1.3 ± 0.6	4.5 ± 1.6
PCB 101/89	1.4 ± 2.5	0.40 ± 0.33	0.17 ± 0.24	1.2 ± 0.24	4.3 ± 1.3
PCB 110	15 ± 26	0.15 ± 0.03	0.19 ± 0.04	0.81 ± 0.27	2.8 ± 0.8
PCB 149	1.7 ± 2.9	0.13 ± 0.18	0.14 ± 0.01	2.0 ± 1.7	7.8 ± 8.5
PCB 118	20 ± 29	2.0 ± 0.72	2.0 ± 0.4	4.3 ± 1.1	15 ± 3
PCB 153	0.3 ± 0.5	0.49 ± 0.64	0.30 ± 0.09	1.5 ± 0.5	5.3 ± 1.8
PCB 138	< 0.4	0.33 ± 0.48	0.19 ± 0.05	0.93 ± 0.46	3.5 ± 2.0
PCB 180	1.6 ± 2.7	0.12 ± 0.16	0.039 ± 0.012	0.78 ± 0.27	2.7 ± 0.9
Total	120 ± 120	6.1 ± 3.2	3.7 ± 0.9	25 ± 4	90 ± 23
Hexachlorocyclohexanes (HCHs)					
α-HCH	160 ± 14	2.0 ± 0.32	1.9 ± 0.2	1.4 ± 0.2	5.1 ± 1.1
γ-HCH	110 ± 18	1.3 ± 0.08	1.1 ± 0.1	1.3 ± 0.2	4.4 ± 0.6
Chlorobenzenes					
Pentachlorobenzene	1.7 ± 1.7	0.66 ± 0.17	0.40 ± 0.00	0.48 ± 0.11	1.7 ± 0.5
Hexachlorobenzene	7.2 ± 3.7	2.3 ± 0.37	2.9 ± 0.0	2.5 ± 0.9	8.5 ± 2.7

[a]obs: obscured due to an analytical interference.

Table 2-3 (continued). HOC concentrations in Peyto Lake water, SPMDs and zooplankton (blank corrected, mean ± 1 SD).

	Water (n = 3) (pg L^{-1})	Triolein SPMDs (ng g^{-1}, lipid weight)		Zooplankton (n = 4)	
		20-d (n = 5)	50-d (n = 2)	(ng g^{-1}, dry weight)	(ng g^{-1}, lipid weight)
DDT isomers					
p,p'-DDE	4.5 ± 4.6	1.8 ± 3.2	0.57 ± 0.08	10 ± 2	36 ± 10
o,p'-DDE	2.5 ± 2.7	0.30 ± 0.09	0.62 ± 0.09	1.8 ± 0.4	6.3 ± 1.5
p,p'-DDT	6.9 ± 6.4	0.93 ± 0.21	2.4 ± 0.5	21 ± 3	75 ± 22
o,p'-DDT	4.4 ± 4.3	0.89 ± 0.24	1.6 ± 0.3	8.1 ± 0.8	29 ± 6
p,p'-DDD	5.6 ± 1.7	1.5 ± 0.26	2.4 ± 0.5	12 ± 2	42 ± 5
o,p'-DDD	4.8 ± 4.2	0.42 ± 0.06	0.82 ± 0.26	3.0 ± 0.5	11 ± 2
Cyclodienes					
cis-Chlordane	3.4 ± 1.1	1.1 ± 0.14	2.4 ± 0.3	7.5 ± 0.7	27 ± 6
trans-Chlordane	1.8 ± 0.6	0.56 ± 0.11	1.5 ± 0.2	4.6 ± 0.6	17 ± 5
cis-Nonachlor	1.2 ± 0.8	0.45 ± 0.06	1.0 ± 0.2	5.3 ± 1.1	19 ± 7
trans-Nonachlor	4.3 ± 0.8	1.3 ± 0.23	2.9 ± 0.4	13 ± 2	46 ± 12
Oxychlordane	0.8 ± 0.8	0.26 ± 0.08	0.66 ± 0.10	0.89 ± 0.23	3.2 ± 1.4
Heptachlor epoxide	19 ± 0.9	0.49 ± 0.70	NA[a]	2.6 ± 0.4	9.2 ± 1.4
α-Endosulfan	25 ± 2.1	0.21 ± 0.30	NA	6.1 ± 2.7	21 ± 7
Dieldrin	21 ± 3.3	0.15 ± 0.13	NA	6.8 ± 0.8	24 ± 3
Endrin	9.8 ± 0.4	0.019 ± 0.027	NA	2.6 ± 0.6	9.2 ± 1.8
Toxaphene					
T2 (B8-1413)	9.6 ± 5.1	2.0 ± 0.39	3.9 ± 0.4	9.4 ± 1.1	33 ± 6
T12 (B9-1679)	25 ± 5.4	2.8 ± 0.56	5.4 ± 0.9	19 ± 2	69 ± 14

[a]NA: not analyzed because of analytical interferences in F3.

Table 2-4. Average HOC concentrations in water, zooplankton, SPMD and sediment blanks.

	Water (pg L^{-1})	Zooplankton (ng g^{-1}, dry weight)	SPMDs (ng g^{-1}, lipid weight)		Sediments (ng g^{-1}, dry weight)
			Triolein	Almond oil	
Polychlorinated biphenyls (PCBs)					
PCB 31/28	16	0.19	1.0	0.57	0.62
PCB 52	obs[a]	< 0.1	0.50	0.050	0.20
PCB 49	obs	< 0.1	0.073	< 0.1	0.13
PCB 70/76	21	0.058	0.23	0.16	0.24
PCB 66/95	23	0.10	0.24	0.15	0.46
PCB 101/89	22	0.21	0.21	0.18	0.13
PCB 110	28	0.33	0.24	0.24	0.16
PCB 149	38	0.32	0.059	0.12	0.16
PCB 118	34	0.35	0.23	0.21	< 0.01
PCB 153	24	0.49	0.25	0.19	0.14
PCB 138	36	0.61	0.22	0.31	0.15
PCB 180	1.7	0.15	0.026	0.041	0.028
Total	360	4.3	5.8	3.7	4.9
Hexachlorocyclohexanes (HCHs)					
α-HCH	0.62	0.021	0.059	0.029	0.026
γ-HCH	1.7	0.030	0.066	0.068	0.047
Chlorobenzenes					
Pentachlorobenzene	< 0.4	< 0.03	0.17	0.13	0.21
Hexachlorobenzene	0.65	0.023	0.064	0.072	0.12

[a]obs: obscured by an analytical interference.

Table 2-4 (continued). Average HOC concentrations in water, zooplankton, SPMD and sediment blanks.

	Water (pg L^{-1})	Zooplankton (ng g^{-1}, dry weight)	SPMDs (ng g^{-1}, lipid weight)		Sediments (ng g^{-1}, dry weight)
			Triolein	Almond oil	
DDT isomers					
p,p'-DDE	14	0.70	0.21	0.36	0.11
o,p'-DDE	2.0	< 0.02	< 0.02	< 0.02	< 0.004
p,p'-DDT	10	0.17	0.15	0.096	0.054
o,p'-DDT	8.5	0.13	0.027	0.013	0.053
p,p'-DDD	1.4	0.16	< 0.02	0.11	0.016
o.p'-DDD	< 0.2	0.023	< 0.02	< 0.02	< 0.004
Cyclodienes					
cis-Chlordane	4.4	0.039	0.058	0.038	0.009
trans-Chlordane	4.0	< 0.02	0.029	< 0.02	0.012
cis-Nonachlor	0.50	0.057	< 0.02	< 0.02	< 0.004
trans-Nonachlor	3.0	0.39	0.010	0.014	0.016
Oxychlordane	0.92	0.089	< 0.02	0.007	0.059
Heptachlor epoxide	< 0.2	0.057	< 0.02	< 0.02	0.019
α-Endosulfan	5.8	0.086	< 0.02	< 0.02	0.062
Dieldrin	5.1	0.26	< 0.02	< 0.02	0.054
Endrin	< 0.2	< 0.02	< 0.02	< 0.02	< 0.004
Toxaphene					
T2 (B8-1413)	< 0.2	0.28	< 0.02	0.017	< 0.004
T12 (B9-1679)	< 0.2	0.39	< 0.02	0.027	< 0.004

Table 2-5. Average HOC concentrations in Bow Lake SPMDs (ng g^{-1}, lipid weight, blank corrected, mean ± 1 SD).

	20-d SPMDs (n = 6)		50-d SPMDs (n = 3)	
	Triolein	Almond oil	Triolein	Almond oil
Polychlorinated biphenyls (PCBs)				
PCB 31/28	0.30 ± 0.13	0.055 ± 0.066	0.21 ± 0.11	0.16 ± 0.03
PCB 52	0.11 ± 0.13	0.13 ± 0.15	0.089 ± 0.090	< 0.1
PCB 49	0.16 ± 0.07	0.027 ± 0.042	0.23 ± 0.03	0.07 ± 0.12
PCB 70/76	0.092 ± 0.048	0.028 ± 0.042	0.14 ± 0.03	0.03 ± 0.03
PCB 66/95	0.21 ± 0.11	0.075 ± 0.055	0.23 ± 0.06	0.12 ± 0.10
PCB 101/89	0.16 ± 0.04	0.15 ± 0.04	0.40 ± 0.05	0.26 ± 0.09
PCB 110	0.11 ± 0.06	0.15 ± 0.13	0.50 ± 0.14	0.24 ± 0.23
PCB 149	0.015 ± 0.022	0.10 ± 0.12	0.33 ± 0.25	0.18 ± 0.22
PCB 118	1.1 ± 0.15	0.82 ± 0.30	1.6 ± 0.2	0.92 ± 0.80
PCB 153	0.048 ± 0.063	0.081 ± 0.071	0.42 ± 0.29	0.29 ± 0.25
PCB 138	0.087 ± 0.13	0.055 ± 0.073	0.47 ± 0.28	0.27 ± 0.27
PCB 180	0.032 ± 0.026	0.028 ± 0.017	0.073 ± 0.064	0.05 ± 0.07
Total	3.1 ± 0.6	3.5 ± 1.4	6.6 ± 1.8	5.2 ± 1.7
Hexachlorocyclohexanes (HCHs)				
α-HCH	1.8 ± 0.2	1.9 ± 0.2	2.8 ± 0.1	2.9 ± 0.3
γ-HCH	1.3 ± 0.1	1.2 ± 0.1	1.7 ± 0.0	1.6 ± 0.1
Chlorobenzenes				
Pentachlorobenzene	0.71 ± 0.19	0.80 ± 0.12	0.61 ± 0.12	0.73 ± 0.19
Hexachlorobenzene	2.5 ± 0.4	2.7 ± 0.4	4.5 ± 0.7	5.0 ± 0.9

Table 2-5 (continued). Average HOC concentrations in Bow Lake SPMDs (ng g^{-1}, lipid weight, blank corrected, mean ± 1 SD).

	20-d SPMDs (n = 6)		50-d SPMDs (n = 3)	
	Triolein	Almond oil	Triolein	Almond oil
DDT isomers				
p,p'-DDE	0.64 ± 0.38	0.35 ± 0.31	0.98 ± 0.22	0.63 ± 0.10
o,p'-DDE	0.25 ± 0.05	0.19 + 0.06	0.47 ± 0.07	0.41 ± 0.03
p,p'-DDT	0.87 ± 0.15	0.74 ± 0.10	1.9 ± 0.2	1.7 ± 0.5
o,p'-DDT	0.69 ± 0.08	0.64 ± 0.10	1.4 ± 0.1	1.3 ± 0.3
p,p'-DDD	1.6 ± 0.12	1.4 ± 0.13	3.0 ± 0.2	2.8 ± 0.5
o.p'-DDD	0.38 ± 0.07	0.39 ± 0.04	1.0 ± 0.1	0.8 ± 0.2
Cyclodienes				
cis-Chlordane	0.70 ± 0.04	0.70 ± 0.07	1.5 ± 0.1	1.4 ± 0.2
trans-Chlordane	0.30 ± 0.04	0.31 ± 0.04	0.64 ± 0.10	0.62 ± 0.06
cis-Nonachlor	0.33 ± 0.04	0.30 ± 0.04	0.81 ± 0.05	0.72 ± 0.12
trans-Nonachlor	0.78 ± 0.09	0.68 ± 0.09	1.5 ± 0.1	1.4 ± 0.2
Oxychlordane	0.15 ± 0.02	0.17 ± 0.03	0.38 ± 0.07	0.35 ± 0.08
Heptachlor epoxide	NA[a]	1.4 ± 0.1	2.4	2.2
α-Endosulfan	NA	3.4 ± 0.0	5.0	5.6
Dieldrin	0.24 ± 0.11	2.4 ± 0.1	4.1	5.3
Endrin	0.08 ± 0.12	0.87 ± 0.01	1.9	1.5
Toxaphene				
T2 (B8-1413)	1.6 ± 0.15	1.4 ± 0.25	3.4 ± 0.2	2.3 ± 1.0
T12 (B9-1679)	2.4 ± 0.19	2.1 ± 0.34	5.2 ± 0.5	4.4 ± 1.0

[a]NA: not analyzed because of analytical interferences in F3.

Table 2-6. Lipid-weight log AFs in SPMDs and zooplankton from Bow and Peyto Lakes.

	log K_{OW}	20-d SPMDs		50-d SPMDs		Zooplankton	
		Bow	Peyto	Bow	Peyto	Bow	Peyto
Polychlorinated biphenyls (PCBs)							
PCB 31/28	5.7[a]	4.8	4.4	4.6	NA[d]	6.0	5.4
PCB 49	5.9[a]	4.3	4.5	4.5	NA	5.2	5.7
PCB 70/76	6.2[a]	4.1	4.1	4.3	3.7	5.6	5.5
PCB 66/95	6.2[a]	4.4	4.7	4.4	4.3	5.8	6.0
PCB 101/89	6.4[a]	4.5	5.5	4.9	5.1	5.9	6.5
PCB 110	6.5[a]	4.2	4.0	4.9	4.1	4.0	5.3
PCB 149	6.7[a]	3.5	4.9	4.8	4.9	6.0	6.7
PCB 118	6.7[a]	4.8	5.0	5.0	5.0	5.5	5.9
PCB 153	6.9[a]	3.6	6.3	4.5	6.2	5.6	7.3
Hexachlorocyclohexanes (HCHs)							
α-HCH	3.8[b]	4.2	4.1	4.4	4.1	4.6	4.5
γ-HCH	3.8[b]	4.1	4.1	4.3	4.0	4.7	4.6
Chlorobenzenes							
Pentachlorobenzene	5.0[c]	5.7	5.6	5.6	5.4	6.4	6.0
Hexachlorobenzene	5.5[c]	5.5	5.5	5.7	5.6	6.3	6.1

[a]Hawker & Connell (1988)
[b]Suntio *et al.* (1988)
[c]Schwarzenbach *et al.* (1993)
[d]NA: not analyzed.

Table 2-6 (continued). Lipid weight log AFs in SPMDs and zooplankton from Bow and Peyto Lakes.

	log K_{OW}	20-d SPMDs		50-d SPMDs		Zooplankton	
		Bow	Peyto	Bow	Peyto	Bow	Peyto
DDT isomers							
p,p'-DDE	5.8[a]	4.6	5.6	4.8	5.1	6.7	6.9
o,p'-DDE	5.8[a]	5.5	5.1	5.8	5.4	6.9	6.4
p,p'-DDT	6.4[b]	5.1	5.1	5.5	5.5	7.1	7.0
o,p'-DDT	6.4[b]	5.6	5.3	6.0	5.6	7.2	6.8
p,p'-DDD	5.5[a]	5.5	5.4	5.7	5.6	7.0	6.9
o.p'-DDD	5.5[a]	5.3	5.0	5.7	5.3	6.8	6.4
Cyclodienes							
cis-Chlordane	6.1[c]	5.6	5.5	5.9	5.9	7.1	6.9
trans-Chlordane	6.2[c]	5.7	5.5	6.0	5.9	7.3	7.0
cis-Nonachlor	6.1[c]	5.4	5.6	5.8	5.9	7.2	7.2
trans-Nonachlor	6.4[c]	5.5	5.5	5.8	5.8	7.1	7.0
Heptachlor epoxide	5.4[d]	NA[f]	4.4	5.2	NA	5.8	5.7
Dieldrin	5.5[b]	4.1	3.8	5.3	NA	6.1	6.1
Endrin	4.6[d]	4.0	3.3	5.4	NA	6.0	6.0
Toxaphene							
T2 (B8-1413)	5.5[e]	5.3	5.3	5.6	5.6	6.6	6.5
T12 (B9-1679)	5.9[e]	4.9	5.0	5.3	5.3	6.4	6.4

[a]Suntio *et al.* (1988)
[b]Schwarzenbach *et al.* (1993)
[c]Simpson *et al.* (1995)
[d]Mackay (1982)
[e]Fisk *et al.* (1999)
[f]NA: not analyzed.

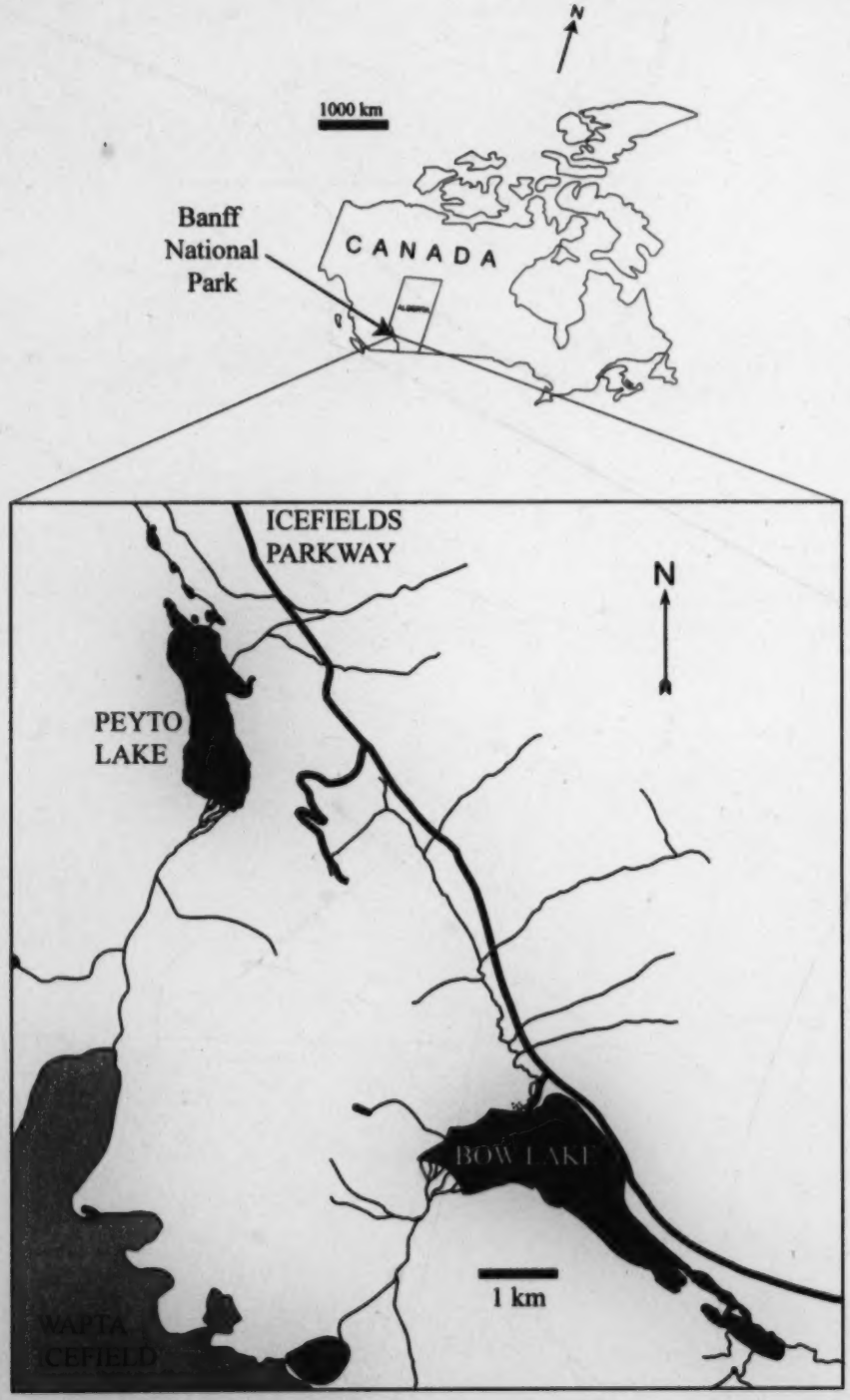

Figure 2-1. Location of Bow Lake and Peyto Lake.

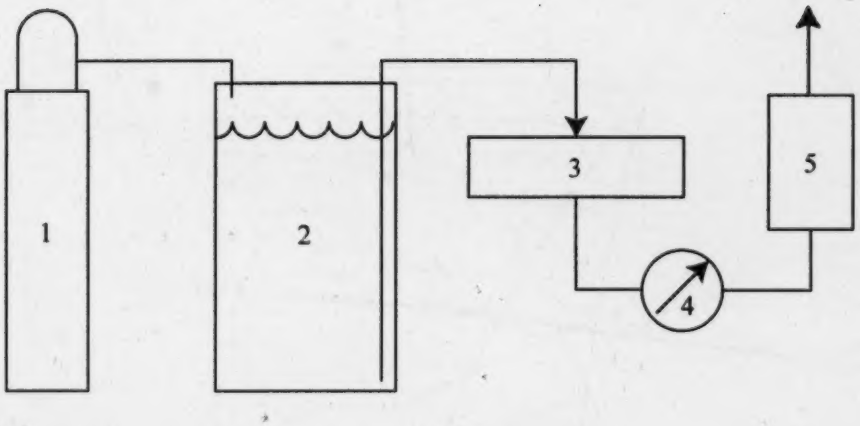

Figure 2-2. Solid-phase extraction (SPE) system. Water in an 18-litre stainless steel vessel (2) is pushed through a filter unit (3) and polyurethane foam (PUF) plug in a stainless steel cylinder (5) by a small cylinder of compressed nitrogen (1). A needle valve (4) is used to control the flow rate through the PUF plug.

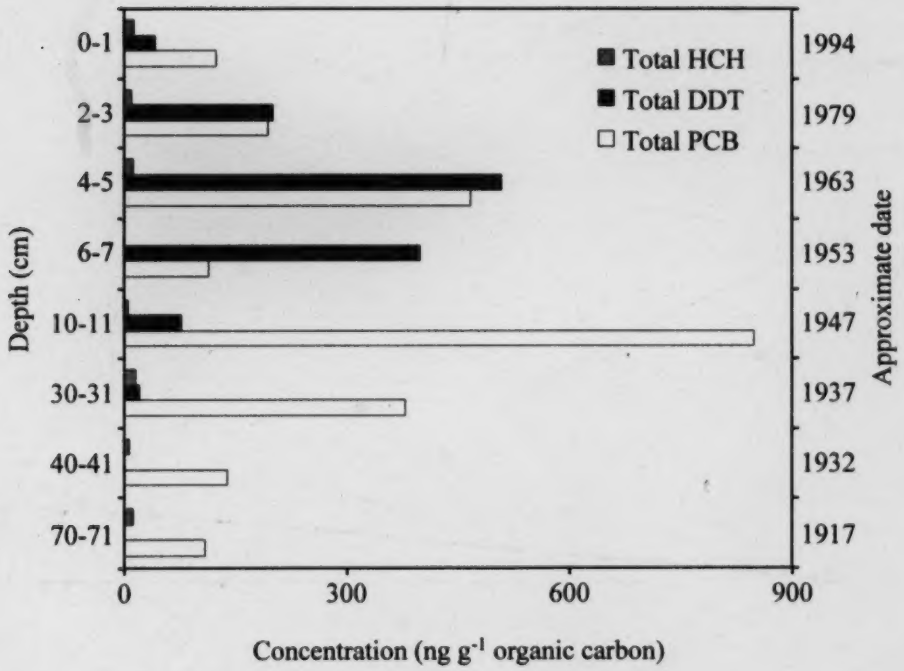

Figure 2-3. Vertical profile of HOCs in Bow Lake sediments.

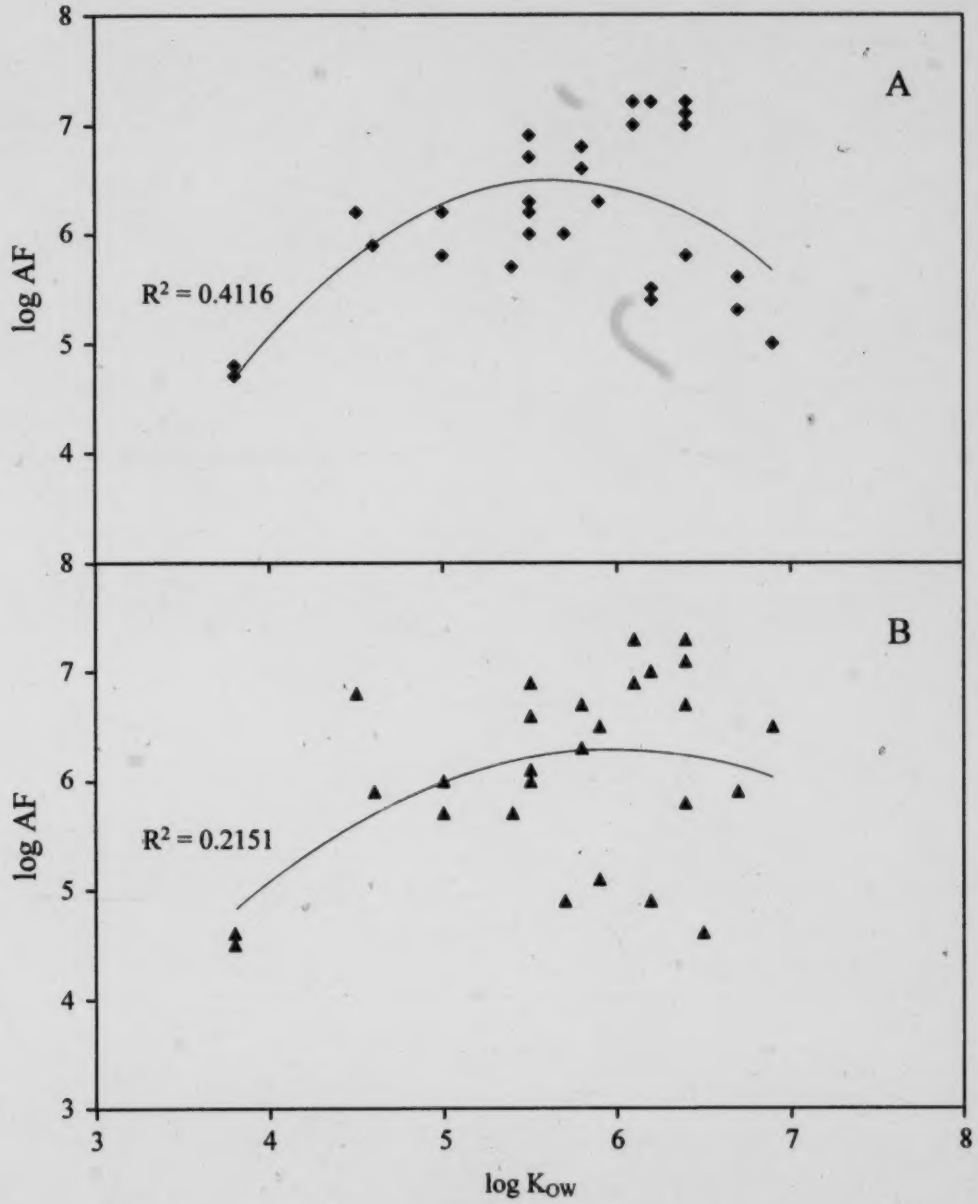

Figure 2-4. Relationship between log AF and log K_{OW} in zooplankton from (A) Bow Lake and (B) Peyto Lake.

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3 Sorption of Hydrophobic Organic Contaminants to Suspended Glacial Particles

Introduction

Glacial meltwaters that flow into subalpine Bow Lake in Alberta, Canada, are a major source of hydrophobic organic contaminants (HOCs) such as chlorinated pesticides and polychlorinated biphenyls (PCBs) that were deposited on the glacier during the past several decades (Donald *et al.* 1999; Blais *et al.* 2001). The meltwaters also supply large amounts of glacial clays to Bow Lake. Sorption of HOCs to these fine, largely inorganic glacial particles can greatly affect their bioavailability and fate: chemicals that are freely dissolved are subject to diffusion-controlled processes such as volatilization and bioconcentration, while HOCs that are associated with particles are subject to advective processes such as settling and ingestion (Gobas & Zhang 1994). The purpose of this study was to investigate the sorption of HOCs to glacial particles.

At the low chemical concentrations typical of the environment, sorption of HOCs is a linear function of the concentration in water

$$C_P = K_{PW} C_W \qquad (3\text{-}1)$$

where C_P is the HOC concentration associated with particles, C_W is the freely dissolved concentration in water and K_{PW} is the particle-water partition coefficient. By convention, concentration units are chosen with the volume unit in solution equivalent in mass to the mass unit for the particles, so that K_{PW} has units of L kg^{-1} or mL g^{-1}. There is continuing debate over whether HOCs are *ad*sorbed to the particle surface or *ab*sorbed within the particle matrix, particularly for systems low in organic carbon (Mingelgrin & Gerstl

1983; Gong *et al.* 1998). The more general term sorption is used to describe any accumulation of dissolved substances by solid phases.

Organic compounds of low aqueous solubility sorb predominantly to organic matter due to its hydrophobicity. The distribution of HOCs between water and particles depends primarily on the organic carbon content of the sorbent and the hydrophobicity of the chemical (Haque & Schmedding 1976; Karickhoff *et al.* 1979). Normalization of K_{PW} to the organic carbon fraction of the particles reduces variability between sediments and allows sorption to be compared to partitioning between water and an organic solvent, such as octanol. A number of empirical relationships between octanol-water partition coefficients (K_{OW}) and sediment organic carbon-water partition coefficients have been derived (Karickhoff *et al.* 1979; Schwarzenbach & Westall 1981; Chiou *et al.* 1983).

In general, empirically derived linear relationships between K_{OW} and organic-normalized sorption can be used for sorbents as low as 0.1% organic carbon (Schwarzenbach & Westall 1981; Barber, II *et al.* 1992; Cornelissen *et al.* 1998). In systems of lower organic carbon, sorption has been observed to be much higher than would be predicted on the basis of organic carbon alone (Schwarzenbach & Westall 1981; Piwoni & Banerjee 1989; Rebhun *et al.* 1992), suggesting that sorption to mineral phases is significant. Sorption in these systems may instead depend on sorbent mineralogy (Mader *et al.* 1997) and surface area, although the relationship between surface area and sorption may be due to the higher relative organic carbon content of smaller particles rather than a physical surface area effect on sorption (Karickhoff *et al.* 1979; Kukkonen & Landrum 1996). Smaller

particle fractions are often enriched in minerals of positive charge, which preferentially sorb organic carbon by complexation with carboxylic and phenolic functional groups (Murphy *et al.* 1990; Barber, II *et al.* 1992). For surfaces completely devoid of organic matter, sorption is generally very low, and dominated by magnetic minerals and swelling clays such as montmorillonite and vermiculite rather than nonmagnetic minerals like quartz and calcite (Schwarzenbach & Westall 1981; Ball & Roberts 1991; Barber, II *et al.* 1992). Mineral surfaces are thought to be poor sorbents of HOCs because they are typically charged and preferentially bind water (Chiou *et al.* 1983).

Although empirical sorption-organic carbon relationships break down for sorbents extremely low in organic carbon, a relationship between sorption and K_{OW} often still exists (Schwarzenbach & Westall 1981). This suggests that sorption is driven by the large increase in entropy that occurs when a chemical sorbs, minimizing exposure of its hydrophobic surface area to water. HOCs dissolved in water are surrounded by a highly structured "iceberg" of water molecules (Frank & Evans 1945). Larger and more hydrophobic molecules produce a greater iceberg, so produce a greater increase in entropy upon sorption, and are more thermodynamically favored.

Because only freely dissolved chemical can be bioconcentrated, it is necessary to develop analytical methods that can distinguish between sorbed and dissolved phases. Conventional methods such as filtration and centrifugation do not adequately separate these phases. The dissolved phase, operationally defined as the filtrate or supernatant, can contain HOCs sorbed to colloids or dissolved organic matter, resulting in overestimation

of the dissolved fraction and decreasing the apparent K_{PW}. In addition, a significant fraction of dissolved chemical can sorb to filters (Hassett & Milicic 1985; Burgess *et al.* 1996; Mouvet & Jücker 1997), resulting in overestimation of the bound fraction. Column chromatography (Landrum *et al.* 1984) can trap unfilterable particles and break weaker chemical-DOM interactions, overestimating the dissolved fraction (Kukkonen & Pellinen 1994). Fluorescence quenching (Gauthier *et al.* 1986) does not physically separate dissolved and bound phases and therefore does not disrupt equilibrium, but is limited to compounds that fluoresce, and chemical concentrations must be near solubility limits for an adequate signal-to-noise ratio. Equilibrium dialysis (Carter & Suffet 1982) also requires high chemical concentrations to get an adequate signal in the aqueous phase, because a significant portion of the chemical sorbs to the dialysis membrane (Harkey *et al.* 1994). Dialysis is also slow, particularly for large compounds that have difficulty diffusing through the membrane (Landrum *et al.* 1984; Huckins *et al.* 1990).

Sparging involves stripping chemicals from solution with an inert gas. It is generally used to determine Henry's law constants (Mackay *et al.* 1979) or to measure desorption kinetics of HOCs from sorbents (Brusseau *et al.* 1990), but it can also be used to determine sorption (Hassett & Milicic 1985; Yin & Hassett 1986; Servos & Muir 1989), because sorbed chemical is not subject to volatilization. Sparging experiments of short duration do not significantly deplete the aqueous phase of chemical, minimizing desorption of HOCs from the sorbents. Many of the analytical artifacts associated with inadequate separation of phases are eliminated. Sparging can be used to determine sorption in two different ways: by measuring the depletion of chemical from the aqueous

phase (Mackay *et al.* 1979), or by collecting volatilized chemical on a suitable sorbent, such as Tenax or XAD-2 (Oliver 1985).

The purpose of this study was to investigate the sorption of HOCs to glacial particles, at a low temperature typical of glacial systems. Two organochlorine compounds were examined; hexachlorobenzene (HCBz) and *p,p'*-dichlorodiphenyltrichloroethane (DDT). Henry's law constants of these two chemicals were determined by measuring both depletion of chemical from water and the amount volatilized, and compared to experimental and calculated values from the literature. K_{PW} values at several particle concentrations were determined by sparging and compared to those determined by conventional batch methods, as well as to empirically derived relationships between K_{OW} and K_{OC}.

Methods

Approximately 60 L of glacial water was collected from the primary stream feeding Peyto Lake. The suspended solids were allowed to settle for at least 2 weeks, and the top 50 L was drawn off and discarded, producing a stock solution with a glacial solids concentration of about 2000 mg L^{-1}. Aliquots of the stock solution were subjected to particle size analysis on a Micromeritics Sedigraph 5100 and for organic carbon determination. Percent loss on ignition (%LOI) was determined by weight difference before and after combustion of dried sediments overnight at 500 °C, and converted to percent organic carbon (%OC) using an empirical relationship developed by Håkansson and Jansson (1983):

$$\%OC = 0.48 \times (\%LOI) - 0.73 \qquad (3\text{-}2)$$

The glacial solids had an organic carbon content of 1.3 ± 0.1%. About 95% of the particles were less than 25 μm in diameter, and 5% were less than 1 μm in diameter.

Experiments were conducted at 6.0 ± 0.1 °C in a temperature controlled room. The sparging vessels were 1-L amber glass jars 10 cm in diameter and 15 cm high (Figure 3-1). Two stainless steel Swagelok bulkhead unions were mounted on the lid to provide an air inlet and outlet. An impactor plate was originally installed in front of the gas outlet, but it was removed because it seemed to collect rather than block aerosolized water.

Radiolabeled chemicals were obtained from Sigma Chemical Co. Reported radiochemical purity was greater than 98%, and the compounds were used without further purification. ^{14}C-DDT (specific activity 12.7 mCi mmol^{-1}) or ^{14}C-HCBz (specific activity 15.9 mCi mmol^{-1}) in acetone was added to 900 mL of water in the sparging vessel and allowed to equilibrate overnight with constant stirring by a Teflon stir bar. Glacial particle concentrations of 0, 130, 250, 500, and 1100 mg L^{-1} in water were examined. The presence of small amounts of acetone (50 μL in 900 mL water) is not expected to affect sorption (Herzel & Murty 1984; Munz & Roberts 1986). Spiking concentrations (0.42 ng mL^{-1} for HCBz, 0.54 ng mL^{-1} for DDT) were approximately an order of magnitude below the water solubility of the chemical at 25 °C (Suntio *et al.* 1988; Mackay *et al.* 1992).

Compressed nitrogen was first bubbled through distilled water to saturate it and prevent water evaporation from the stripping vessel. It was then introduced at a flow rate of 200-500 mL min^{-1}. into the bottom of the sparging vessel through a stainless steel HPLC

filter. Gas flow rates were constantly monitored with a Humonics Veri-Flow 500 electronic flow meter. An Amberlite XAD-2 column (6 mm in diameter and 50 mm long, containing approximately 0.8 g resin) collected the sparged compound at the top of the vessel. The XAD-2 was cleaned before use by Soxhlet extraction for 24 h each in dichloromethane and methanol. After use, the XAD-2 column was eluted with 10 mL hexane. The hexane eluate was mixed with 10 mL scintillation cocktail (ACS, Amersham) and counted on a Beckman 6500 liquid scintillation counter (LSC) with automatic quench correction. Ten-millilitre water samples were taken before sparging began and approximately every 30 min during the experiments, which were approximately 3 h in duration. Scintillation cocktail was added to each aliquot and the samples were counted.

Air-water partition coefficients were measured by monitoring the depletion of the compound from the aqueous phase (Mackay *et al.* 1979):

$$\ln\left(\frac{C}{C_0}\right) = -\frac{HQ_A t}{RTV_W} = -\frac{K_{AW}Q_A t}{V_W} \qquad (3\text{-}3)$$

where t is time, C is aqueous concentration (C_0 is aqueous concentration at the start of the experiment, t = 0), H is the Henry's law constant of the chemical, Q_A is the gas flow rate, R is the gas constant (8.31451 Pa m^3 mol^{-1} K^{-1}), T is temperature (K), and V_W is the volume of water in the sparging vessel. Ln C/C_0 was graphed against $Q_A t/V_W$ to yield the air-water partition coefficient K_{AW}. Air-water partition coefficients were also determined as the ratio of chemical collected on the XAD-2 column to the concentration in water at the end of the experiment, divided by the total volume of gas sparged. Henry's law

constants at 6°C were estimated by ratios of vapor pressure to aqueous solubility obtained from Paasivirta *et al.* (1999).

The particle-water partition coefficient K_{PW} was calculated using the following equation (Yin & Hassett 1986):

$$K_{PW} = \frac{K_{AW} - K_{AW}'}{K_{AW}'S} \qquad (3\text{-}4)$$

where K_{AW} is the air-water partition coefficient determined in particle-free water, and K_{AW}' is the apparent air-water partition coefficient in the presence of particles of concentration S (refer to Appendix 1 for full derivation).

Batch sorption experiments were carried out in 15-mL glass centrifuge tubes. Caps were lined with aluminum foil to prevent sorption to the Teflon lining (Keeley *et al.* 1986; Murphy *et al.* 1990). Radiolabeled DDT or HCBz in acetone (10 μL) was added to 10 mL of water in each test tube. Test tubes were rotated at 5 rpm for 24-48 h, then centrifuged at 2000 rpm (~1200 g) for 30 min, and the supernatant was assayed by LSC. The particle-water partition coefficient was calculated by expressing Equation 3-4 in terms of water concentrations rather than air-water partition coefficients:

$$K_{PW} = \frac{C_W - C_W'}{C_W'S} \qquad (3\text{-}5)$$

where C_W is the concentration of chemical in particle-free water, and C_W' is the concentration of chemical in the supernatant in the presence of particles of concentration S.

Particle-water partition coefficients were converted to organic carbon-water partition coefficients (K_{OC}) according to

$$K_{OC} = \frac{K_{PW}}{F_{OC}} \qquad (3\text{-}6)$$

where F_{OC} is the organic carbon fraction of the particles. K_{OC} values were then compared with empirically derived relationships between K_{OW} and K_{OC}:

$$\log K_{OC} = \log K_{OW} - 0.21 \text{ (Karickhoff } et\ al. \text{ 1979)}$$

$$\log K_{OC} = 0.72 \log K_{OW} + 0.49 \text{ (Schwarzenbach \& Westall 1981)}$$

Results and Discussion

For DDT, Henry's law constants determined experimentally at 6 °C agreed reasonably well with literature values at 20-25 °C (Table 3-1). This was unexpected, because Henry's law constants approximately double for each 10 °C increase in temperature (Burkhard *et al.* 1985; Munz & Roberts 1987; Kucklick *et al.* 1991; ten Hulscher *et al.* 1992). Henry's law constants at room temperature (20-25 °C) should therefore be about 3-4 times higher than those at 6 °C. Once corrected for temperature, experimentally determined Henry's law constants for HCBz agreed very well with the value reported by Atlas *et al.* (1982), but were higher than other reported values (Table 3-1). The experimentally determined values for both chemicals were considerably lower than those estimated by ratios of vapour pressure to aqueous solubility from Paasivirta *et al.* (1999), which are believed to be fairly accurate for hydrophobic chemicals (Mackay & Shiu 1981).

One of the primary assumptions of sparging is that the chemical is at equilibrium between the air and water phases by the time an air bubble reaches the top of the water column (Mackay *et al.* 1979). If equilibrium is not attained, H will be underestimated, resulting in the overestimation of the chemical concentration in water and underestimation of K_{PW} (Servos & Muir 1989). Equilibrium of chemical between the gas bubbles and the water is dependent on bubble size and water column depth (Li *et al.* 1993). Yin and Hassett (1986) found that equilibrium of mirex occurred at a water column height of 14 cm. Dunnivant *et al.* (1988) determined H for several PCBs, and found no differences in H measured at water column heights of 8, 18 and 28 cm. They suggested that the use of a diffuser to make small air bubbles was more important than water column height. For benzene, Mackay *et al.* (1979) found that each 10 cm depth yielded an 80% approach to equilibrium, while Li *et al.* (1993) calculated 99% equilibrium for a water column depth of 6 cm and 1 mm bubbles with rapid stirring. A vigorously stirred system not only ensures a homogeneous liquid phase, but also forms a vortex, which increases the residence time of the bubbles in the water column and ensures adequate contact time for equilibration (Li *et al.* 1993; Koelmans *et al.* 1995). The depth of water needed to achieve equilibrium decreases with temperature, because chemicals of lower H approach equilibrium faster, and H decreases with temperature (Mackay *et al.* 1979). Therefore, although the height of the water column (from frit to surface) in this system was only about 10 cm, equilibrium between the air and water phases was assumed because chemicals of low H were examined at low temperature, air was introduced with a diffuser and the system was vigorously stirred.

The use of sparging in determining sorption is based on the assumption that the chemical-sorbent complex is not subject to volatilization. While this is technically true, bursting bubbles at the water surface can aerosolize water and particles (Murray & Andren 1991; Friesen *et al.* 1993), which are then collected on the sorbent column, resulting in overestimation of C_A (and therefore H). This effect is greatest for compounds of low H (Gong & DePinto 1992; Friesen *et al.* 1993), and increases with gas flow rate (Gershey 1983). K_{AW} determined by collection of volatilized chemical on XAD-2 increased with flow rate for both DDT and HCBz (Figure 3-2), suggesting that aerosol-mediated transport occurred. The increase was most pronounced for DDT, which was expected due to its lower Henry's law constant. A similar increase with flow rate was not observed for K_{AW} determined by depletion from water. Measurement of a chemical depletion rate from the aqueous phase does not appear to be as sensitive to aerosol-mediated transport artifacts, possibly because water has a greater chemical carrying capacity than air.

Other techniques for determining Henry's law constants, such as the static equilibration of chemical between water and air in a closed system (EPICS, Lincoff & Gossett 1984) and wetted-wall column methods (Fendinger & Glotfelty 1988) are not subject to aerosol-mediated transport effects. However, EPICS is limited to chemicals of high volatility, and wetted-wall column techniques probably cannot be used to determine particle sorption, because the particles may stick to the sides of the column and disrupt water flow. Ashworth *et al.* (1988) found good agreement between static and dynamic (EPICS and sparging) methods. This suggests that aerosol-mediated transport artifacts can be reduced or eliminated, perhaps by increasing the distance between the water surface and the

collection column or by inserting barriers such as impactor plates or glass wool plugs. However, glass wool may adsorb a significant fraction of volatilized chemical because of its high surface area, resulting in the underestimation of volatilization rates.

It is also assumed that gas sparging does not disturb particle-water equilibrium. Depletion of solute from the aqueous phase by sparging follows first-order kinetics (Karickhoff 1980; Coates & Elzermann 1986). If sparging is continued for extended periods of time, the aqueous HOC concentration will approach zero, and chemical will begin to desorb from the solids, resulting in non-first-order behavior (Coates & Elzermann 1986; Cornelissen *et al.* 1998; ten Hulscher *et al.* 1999). Depletion curves were linear for both chemicals (Figure 3-3), suggesting that desorption from particles did not occur.

For DDT, Henry's law constants determined by collection of chemical on XAD-2 were lower than those determined by depletion of chemical from water (Table 3-1), when they should have been higher, due to aerosol-mediated transport effects. Low Henry's law constants determined by collection on XAD-2 may have been due to leaks in the system, poor trapping of the chemicals by the XAD, poor extraction efficiency of the chemicals from the XAD after sparging, or non-equilibrium conditions. The system was checked for leaks before each sparging experiment. XAD-2 resin has been shown to extract HOCs from air with high efficiency (Doskey & Andren 1979), and is used frequently in air-sampling programs. Other researchers (Oliver 1985; ten Hulscher *et al.* 1992) have extracted sparging collection columns with hexane, as was done here, apparently with high efficiency, although they used Tenax rather than XAD-2. A more polar solvent such

as acetone may have extracted DDT from the XAD-2 with greater efficiency. Spiking the treatments the day before the experiment may not have allowed sufficient time for the chemical to equilibrate with the particles and the sparging vessel: the measured depletion from water may have been be due to both volatilization and slow diffusion of chemical into particles. However, the time required to reach steady state is related to the organic carbon content of the particles (Karickhoff & Morris 1985; Coates & Elzermann 1986; Lick & Rapaka 1996; Cornelissen *et al.* 1998). Sediments high in organic matter approach equilibrium slowly due to slow diffusion of the chemical into the organic carbon matrix (Bouchard *et al.* 1988). Equilibrium would be reached faster in the low organic carbon particles used in these experiments than those higher in organic carbon, and may be aided by vigorous stirring. For HCBz, Henry's law constants determined by depletion of chemical from water were approximately equal to those determined by collection of chemical on XAD-2 (Table 3-1), suggesting that equilibrium between the water and particles was reached.

There were also differences between the two methods in the calculation of K_{PW} (Table 3-2). For chemical collected on XAD-2, the apparent volatilization rate K_{AW}' was sometimes higher than the volatilization rate in particle-free water, resulting in negative values of K_{PW}. Like Henry's law constants determined by collection on XAD-2, this effect is probably also due to aerosol-mediated transport. Water solutions containing particles aerosolize particles in proportion to their concentration in water, resulting in higher apparent volatilization rates than if there were no particles in the water.

A cursory visual examination of the XAD-2 columns revealed no trapped particles, although water was present. The presence of water in the column tended to impede gas flow, and the errors associated with poor maintenance of gas flow rates may have caused greater errors than the presence of water or particles. Li *et al.* (1993) suggested using an internal standard to control for such variables as flow rate and temperature fluctuations.

K_{PW} values determined by batch sorption were significantly lower than those determined by sparging (depletion from water method) for both chemicals (Table 3-3). This may have been due to nonequilibrium conditions or inadequate phase separation by centrifugation, resulting in overestimation of C_W'. In addition, the amount sorbed was calculated indirectly, by comparing aqueous chemical concentrations in treatments with and without sediment. Subtracting two relatively large numbers to obtain the small mass sorbed is inherently imprecise (Piwoni & Banerjee 1989). The samples were too small to allow the analysis of the solid phase in order to confirm the fate of the sorbate.

Determination of sorption by sparging relies on the independent determination of the Henry's law constant in particle-free water, as a reference state to compare with water containing particles. However, except in ultra-clean facilities, dust is inevitably present, and sorption to such material in the reference water will result in the underestimation of Henry's law constants, particularly for very hydrophobic chemicals. It would be desirable to find a way to measure sorption without having to rely on independent determinations of properties in "particle-free" water.

K_{PW} can be determined by measuring the reduction in volatilization rate with increasing particle concentration. The apparent K_{AW} (K_{AW}' in Equation 3-4) is reduced by the factor $(1 + K_{PW}S)^{-1}$ in the presence of particles (Podoll & Mabey 1987). Equation 3-4 can be modified to yield K_{PW} from air-water partition coefficients determined at several particle concentrations:

$$K_{PW} = \frac{K_{AW(S_i)} - K_{AW(S_{i+n})}}{K_{AW(S_{i+n})}(S_{i+n} - S_i)} \qquad (3\text{-}7)$$

where S_{i+n} is a higher particle concentration than S_i. If K_{PW} is assumed constant, then graphing $\frac{K_{AW(S_i)} - K_{AW(S_{i+n})}}{K_{AW(S_{i+n})}}$ against $(S_{i+n} - S_i)$ will yield a straight line of slope K_{PW}.

Equation 3-5 was similarly modified:

$$K_{PW} = \frac{C_{W(S_i)} - C_{W(S_{i+n})}}{C_{W(S_{i+n})}(S_{i+n} - S_i)} \qquad (3\text{-}8)$$

and $\frac{C_{W(S_i)} - C_{W(S_{i+n})}}{C_{W(S_{i+n})}}$ graphed against $(S_{i+n} - S_i)$ to a straight line of slope K_{PW}.

Due to aerosol-mediated transport artifacts, K_{PW} was derived from measurements of depletion rate rather than collection on XAD-2. A "solids effect," where K_{PW} decreases with increasing S (O'Connor & Connolly 1980), was not observed: Equations 3-7 and 3-8 produced strong linear relationships (Figure 3-4, Table 3-4), with the exception of the sparging experiment for HCBz. The poor linear relationship can be attributed to the high apparent K_{AW} of HCBz at the highest particle concentration. If this data point is removed, R^2 values improve and K_{PW} increases to 605 ± 54 ($S_i = 0$ only, $R^2 = 0.9920$, $n = 3$), 583 ± 79 ($S_i = 0$ not included, $R^2 = 0.9819$, $n = 3$), and 649 ± 161 ($S_i = 0$ included, $R^2 = 0.8022$,

n = 6). Because Equations 3-7 and 3-8 are based on the assumption that K_{PW} is constant, their applicability is limited to systems or particle concentration ranges in which a solids effect does not occur.

K_{PW} was greater for DDT than HCBz, suggesting a relationship with K_{OW}. Sorption coefficients determined by sparging (Table 3-4) and converted to K_{OC} values agreed well with the empirical relationship of Schwarzenbach and Westall (1981), but were considerably lower than those calculated from Karickhoff *et al.* (1979) (Table 3-5). The K_{OC} value for HCBz from this experiment was still lower than either empirical relationship, suggesting that glacial organic carbon has a lower sorption capacity than other organic carbon. Although the relationship between K_{OW} and K_{OC} implicitly assumes that HOCs have equal affinity for all organic matter, sorption is dependent on the molecular size and polarity of the organic matter, which can vary with its source (Chiou *et al.* 1986; Grathwohl 1990). The relationship of Schwarzenbach and Westall (1981) was derived using low organic carbon sediments, and was therefore more applicable to the system studied here.

The low sorptive ability of glacial particles has important implications for contaminant bioavailability and fate. The ability of a rapidly moving stream to carry HOCs is high, due to the high concentration of suspended solids. However, dilution of the stream by lake water reduces the carrying capacity of the stream and results in the transfer of HOCs into the aqueous phase (Squillace & Thurman 1992). A large fraction of HOCs may be sorbed in glacial streams due to high solids concentration, and desorb once they reach the

lake. In addition, decreased temperature favours partitioning into the particulate phase (Schwarzenbach *et al.* 1993; Bergen *et al.* 1993). The OCs may be bound in the glacial stream, but may desorb when they reach the warmer lake. The low inertia of sorption of the low organic sediments in Bow Lake suggests that these chemicals rapidly desorb, making them available for bioconcentration soon after they enter the lake.

Conclusions

Sorption of HOCs to glacial clays was quite low because of the low organic carbon content of the particles. Sorption coefficients determined by batch sorption were lower than those determined by sparging, possibly due to incomplete phase separation. Collecting volatilized chemical on XAD-2 was less accurate than measuring depletion of chemical from water due to aerosol-mediated transport. No "solids effect" was observed: the linear relationship between sorption and particle concentration allowed the determination of sorption coefficients by measuring the decrease in apparent K_{AW} with particle concentration.

Table 3-1. Comparison of experimental Henry's law constants from this study with literature values (Pa m^3 mol^{-1}, mean ± 1 SD).

	DDT	HCBz
Experimental (6 °C, depletion from water)	5.6 ± 1.9 (n = 4)	25 ± 1.9 (n = 5)
Experimental (6 °C, collected on XAD-2)	1.1 ± 0.3 (n = 4)	35 ± 14 (n = 5)
Paasivirta *et al.* (1999) (6 °C)	8.8	140
Fendinger *et al.* (1989) (23 °C)	1.2	
ten Hulscher *et al.* (1992) (20 °C)		41
Oliver (1985) (20 °C)		49
Atlas *et al.* (1982) (23 °C)		130
Suntio *et al.* (1988) (Recommended, 20 °C)	2.4	7.1

Table 3-2. K_{PW} determined by sparging (mL g^{-1}, range, n = 2).

	DDT		HCBz	
Particle concentration (mg L^{-1})	Depletion from water	Collected on XAD-2	Depletion from water	Collected on XAD-2
130	670	-1100 – -2200	410 – 730	-1300 – 2000
250	280 – 1200	-190 – -220	460 – 530	-320 – 450
500	740 – 940	-110 – 320	430 – 710	220 – 500
1100	1200 – 1900	220 – 260	73 – 370	250 – 370

Table 3-3. K_{PW} determined by batch sorption (mL g^{-1}, mean ± 1 SD, n = 3).

Particle concentration (mg L^{-1})	DDT	HCBz
230	480 ± 88	330 ± 28
450	390 ± 120	270 ± 41
680	650 ± 120	260 ± 80
1100	600 ± 70	240 ± 120

Table 3-4. K_{PW} determined by Equations 3-7 and 3-8 (mL g^{-1}, mean ± 1 SD).

	DDT				HCBz			
	Sparging		Batch sorption		Sparging		Batch sorption	
	K_{PW}	R^2	K_{PW}	R^2	K_{PW}	R^2	K_{PW}	R^2
$S_i = 0$ only (n = 4)	1600 ± 190	0.973	660 ± 87	0.967	360 ± 66	0.937	200 ± 5	0.999
$S_i = 0$ not included (n = 6)	1700 ± 93	0.988	580 ± 130	0.827	240 ± 78	0.704	180 ± 12	0.983
$S_i = 0$ included (n = 10)	1600 ± 92	0.976	620 ± 70	0.907	290 ± 86	0.582	210 ± 25	0.900

Table 3-5. Comparison of experimental K_{OC} values with empirically derived relationships.

Compound	log K_{OW}	log K_{OC} (this study)	log K_{OC} (Karickhoff *et al.* 1979)	log K_{OC} (Schwarzenbach & Westall 1981)
HCBz	5.5	4.3	5.3	4.5
DDT	6.4	5.1	6.2	5.1

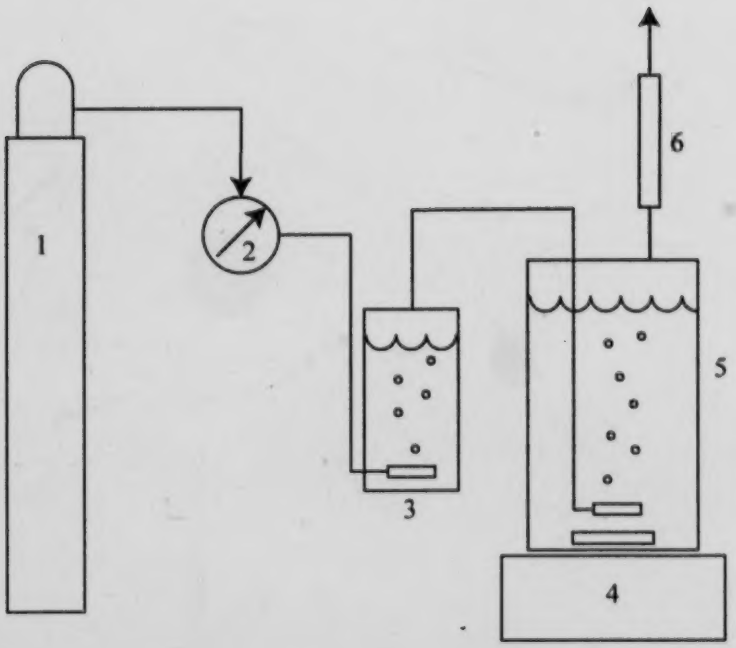

Figure 3-1. Sparging apparatus. Compressed nitrogen (1) passes through a flow meter (2) and is hydrated in a smaller sparging vessel (3) before entering the main sparging vessel (5). Volatilized chemical is collected on an XAD-2 column (6). The particle-water mixture is kept suspended with a stirrer (4).

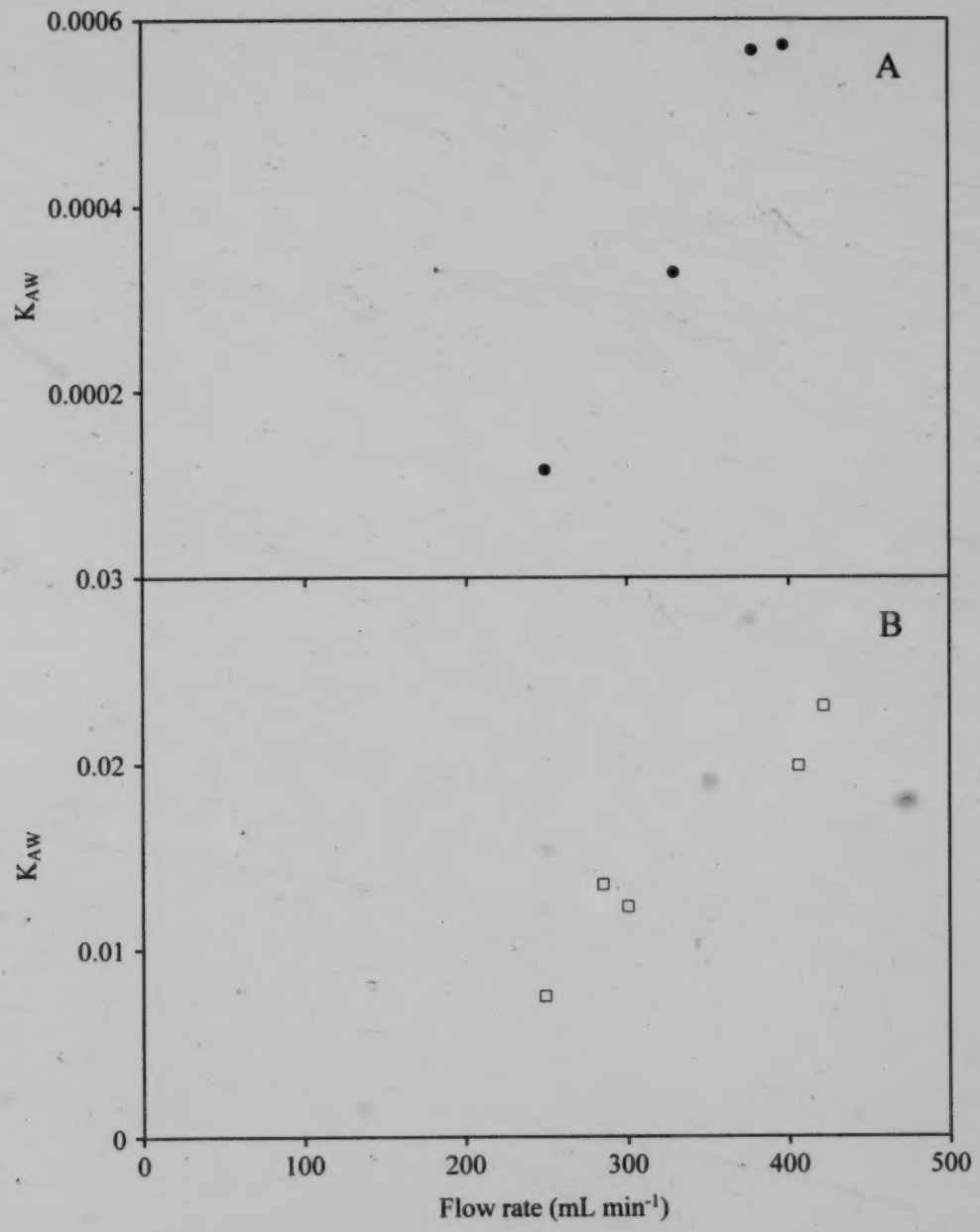

Figure 3-2. Relationship between K_{AW} and sparging gas flow rate for (A) DDT and (B) HCBz collected on XAD-2.

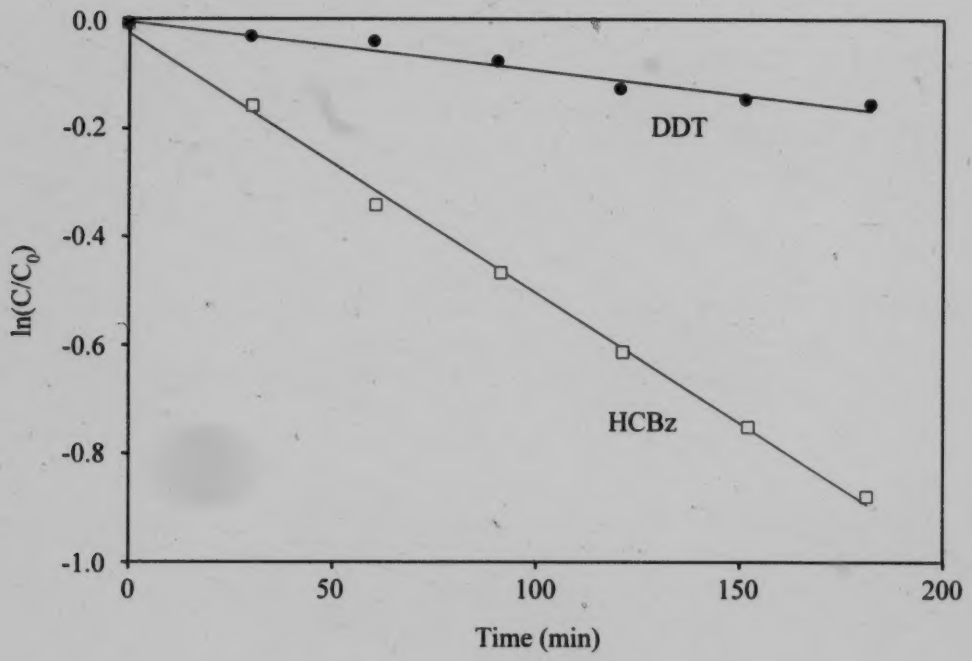

Figure 3-3. Depletion of (●)DDT and (□) HCBz from an aqueous solution containing 250 mg L^{-1} glacial particles.

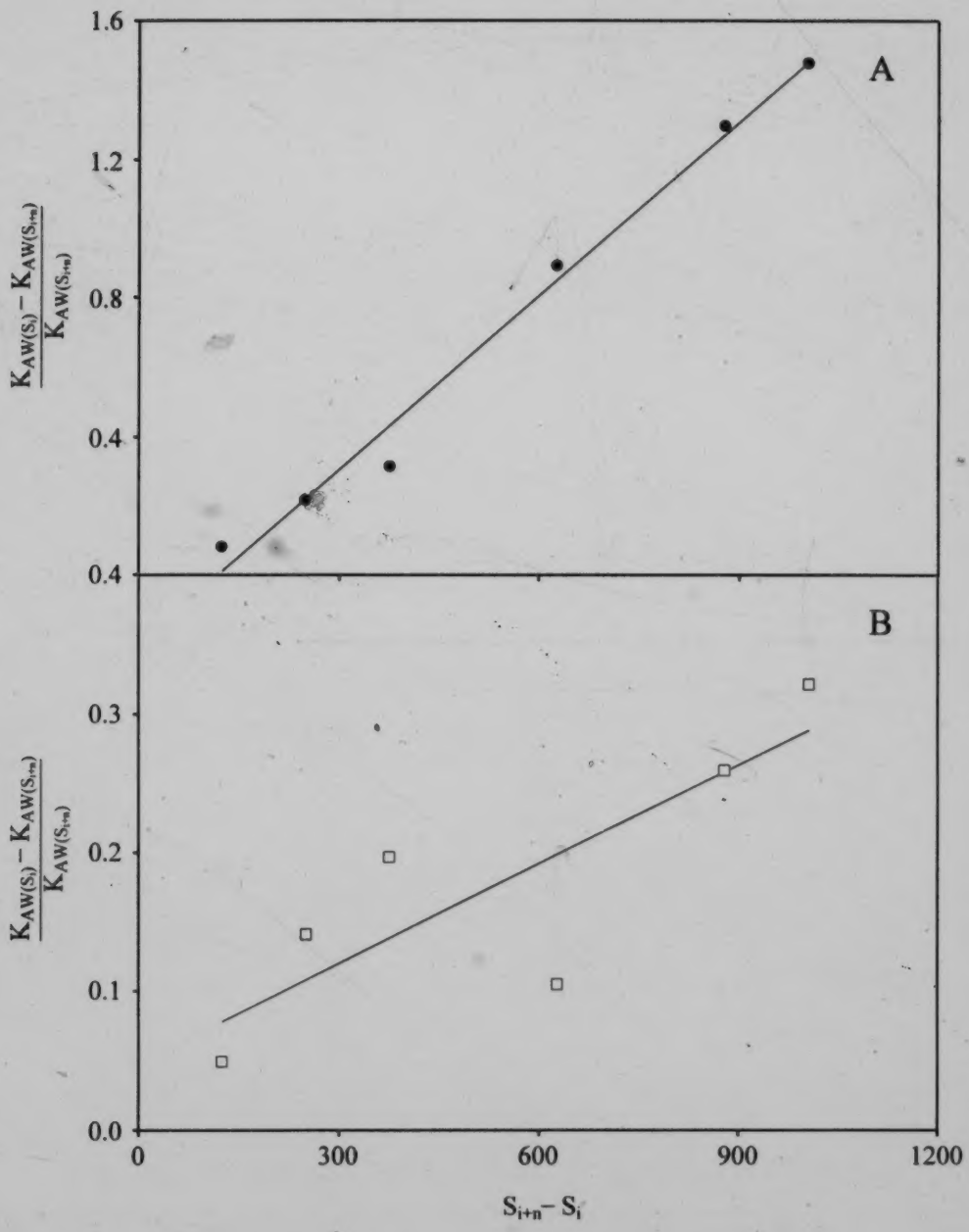

Figure 3-4. Determination of K_{PW} from the decrease in volatilization rate with particle concentration for (A) DDT and (B) HCBz ($S_i = 0$ not included).

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4 Uptake and Elimination of Hydrophobic Organic Contaminants by *Hesperodiaptomus arcticus* (Crustacea: Copepoda) in the Presence of Suspended Glacial Particles

Introduction

Lake trout (*Salvelinus namaycush*) from subalpine Bow Lake have higher concentrations of hydrophobic organic contaminants (HOCs) such as chlorinated pesticides and polychlorinated biphenyls (PCBs) than those from other lakes in the Canadian Rocky Mountains (Donald *et al.* 1993). These high concentrations are not due to biomagnification via an exceptionally long food chain: typically, HOC concentrations in zooplankton are much lower than in predatory fish (Kidd *et al.* 1995), but trout and zooplankton from Bow Lake have similar HOC concentrations (Campbell *et al.* 2000).

Some characteristics of Bow Lake make its biota particularly susceptible to contamination by HOCs. The low average temperature of Bow Lake (due to its high elevation, ~2000 m above sea level) results in increased atmospheric deposition of HOCs (Blais *et al.* 1998), and the short ice-free season inhibits their evaporation (Swackhamer *et al.* 1988). In addition, glacial melt that flows into Bow Lake in the summer contains HOCs that were deposited on the glacier during the past several decades (Donald *et al.* 1999; Blais *et al.* 2001).

The meltwaters also supply large amounts of glacial clays to Bow Lake. Sorption of HOCs to these fine, largely inorganic particles can greatly affect their bioavailability and fate: chemicals that are freely dissolved are subject to diffusion-controlled processes such

as volatilization and bioconcentration, while HOCs that are associated with particles are subject to advective processes such as settling and ingestion (Gobas & Zhang 1994). *Hesperodiaptomus arcticus*, a large copepod found at relatively high densities in Bow Lake, ingests large amounts of glacial clays, as shown by gut contents (Campbell 1996) and the large proportion of fecal pellets in Bow Lake sediments (Smith & Syvitski 1982). In this study, we examined whether high HOC concentrations in *H. arcticus* were due to ingestion of glacial particles.

HOCs can be accumulated through bioconcentration, where freely dissolved chemical diffuses into the lipid compartments of the organism until thermodynamic equilibrium is achieved (Hamelink *et al.* 1971; Clayton, Jr. *et al.* 1977). The concentration in the organism is generally controlled by the hydrophobicity (as measured by the octanol-water partition coefficient, K_{OW}) and persistence of the chemical and the lipid content of the organism. Lipid-rich organisms therefore accumulate high concentrations of recalcitrant HOCs (Roberts *et al.* 1977). Although the concentration of most HOCs in water is low, significant body burdens can develop because aquatic animals must ventilate large water volumes (several times their body weight each day) to satisfy their oxygen requirements.

Material in the water column that sorbs HOCs, whether suspended particles (Eaton *et al.* 1983; Schrap & Opperhuizen 1990) or dissolved organic carbon (DOC) (Leversee *et al.* 1983), hinders the bioconcentration of HOCs, because the chemical-sorbent complex is too large to diffuse through biomembranes (Black & McCarthy 1988). Uptake experiments can be used to estimate freely dissolved HOC concentrations, because the

reduction in uptake is proportional to the fraction of HOC sorbed. The fraction of chemical that is sorbed is a function of the organic carbon content of the sorbent and the hydrophobicity of the chemical (Karickhoff *et al.* 1979). Sediments that are high in organic carbon reduce bioconcentration (McLeese *et al.* 1980; Boese *et al.* 1995), and more hydrophobic chemicals are affected to a greater extent than relatively water-soluble chemicals (Leversee *et al.* 1983).

Sorbed chemicals may be accumulated if they are ingested. Uptake from both food and water is referred to as bioaccumulation. It has been shown both theoretically (Spacie & Hamelink 1985; Gobas *et al.* 1988) and experimentally (Rhead & Perkins 1984; Fisher & Clark 1990) that uptake from food and water is additive. The importance of uptake from food depends on the feeding rate, assimilation efficiency (which can vary with feeding rate), concentration in the food and food quality (Thomann 1989; Landrum *et al.* 1992b).

Estimating assimilation efficiency of ingested HOCs by small invertebrates is difficult, due to difficulties in determining the amount of chemical ingested. The HOC concentration on ingested particles may not be equal to the bulk sediment concentration, because *H. arctica* and other crustaceans selectively ingest particles based on size or nutritional value (organic carbon content), and HOCs differentially sorb to particles of different sizes and organic carbon contents (Kukkonen & Landrum 1996). A dual tracer method (Klump *et al.* 1987) of estimating assimilation efficiency has the same limitations. This method utilizes two radiolabeled chemicals, one that is assimilated and one that is not. Each tracer must be ingested at the same rate, but this often does not occur

due to unequal sorption of each tracer (Lydy & Landrum 1993). Because HOCs sorb predominantly to organic carbon (Karickhoff *et al.* 1979), organic carbon can also be used as a tracer (Lee, II *et al.* 1990). However, this requires the assumption of an organic carbon assimilation efficiency, which is not any more justifiable than simply assuming a HOC assimilation efficiency (Penry 1998).

Gobas *et al.* (1993) proposed a model of contaminant uptake through food. When food entering the gastrointestinal tract (GIT) is digested, carbon is absorbed for energy, and the volume and fugacity capacity of the remaining food decreases. The increase in fugacity within the GIT creates a fugacity gradient that allows diffusion of hydrophobic chemicals from the GIT into the organism. The model suggests that particles must have nutritional value (i.e. relatively high organic carbon) for organisms to assimilate contaminants via ingestion, which is supported by the observed increase in HOC assimilation efficiency with food digestibility (Bruner *et al.* 1994b).

Feeding itself can produce effects that complicate the determination of the relative importance of water and food in determining HOC body burdens. Either feeding or starving organisms during bioaccumulation experiments can result in physiological changes that affect both uptake and elimination rates (Jimenez *et al.* 1987; Weston 1990; Harkey *et al.* 1997). Ingestion of uncontaminated solid material appears to increase HOC elimination rates (Landrum & Robbins 1990). Several investigators (Leversee *et al.* 1982; Landrum 1982; Landrum & Scavia 1983) have found that aquatic invertebrates eliminate HOCs faster in the presence of a substrate than in clear water, although the effect is not

broadly predictable (Landrum *et al.* 1992a; Harkey *et al.* 1994). Fish retain a higher proportion of a chemical if it is in a smaller amount of food, suggesting that some is lost through fecal elimination (Clark & Mackay 1991). Ingestion of a non-absorbable lipid substitute (olestra) increases the fecal egestion rate of HOCs (Moser & McLachlan 1999). The non-absorbable lipid substitute maintains a high fugacity capacity in the GIT, resulting in a net transfer of chemical from the organism to the GIT and its subsequent release by egestion. Copepods may increase the fugacity capacity of ingested low organic carbon material such as glacial flour by enclosing their feces within a peritrophic membrane, resulting in a decrease in fugacity of the GIT and diffusion of contaminant out of the tissues and into the GIT. The peritrophic membrane has been suggested as a means of elimination of xenobiotics in other invertebrates (Abedi & Brown 1961).

Bioaccumulation is characterized by a bioaccumulation factor (BAF), which can be determined by several methods. The simplest is to expose the organism to a constant concentration of the chemical in water and allow the system to reach equilibrium. The BAF is then the ratio of chemical concentration in the organism C_B to its concentration in water C_W. However, HOCs generally approach equilibrium very slowly; the time required to reach equilibrium increases with chemical hydrophobicity, and may exceed the lifetime of the study organism (Hawker & Connell 1985). There are also problems associated with maintaining a constant contaminant concentration in water over a long period, even when flow-through conditions are used (McCarthy & Jimenez 1985).

Bioaccumulation factors can also be described as the ratio of uptake and elimination rates. Experiments using this method do not require equilibrium to be achieved, and give similar results to the equilibration method (Southworth *et al.* 1978; Bishop & Maki 1980). Both uptake and elimination rates can be determined in a single experiment by nonlinear regression of a longer uptake experiment, provided there are sufficient data points to fit a curve with confidence (Gobas & Zhang 1992). However, fitting a curve requires initial parameter estimates, and the iterative procedure may converge on unrealistic uptake and elimination rates, particularly if the initial parameter estimates are poor (Spacie & Hamelink 1985). In addition, asymptotic uptake curves can be displayed by a number of different processes, including equilibrium and decreased uptake due to toxicity or a reduction in bioavailability (Landrum *et al.* 1992b). Measuring uptake and elimination rates in separate experiments can more easily differentiate these processes, and it is far simpler and more intuitively meaningful to fit a line than it is to fit a curve. A simple linear regression also provides a confidence interval for the slope of the line.

The specific objectives of this study were to examine whether HOC sorption to glacial particles increases uptake because of particle ingestion or reduces uptake by decreasing the fraction of freely dissolved chemical; to determine the effect of sediment ingestion on HOC elimination rates; and to evaluate the potential of uptake experiments to measure freely dissolved concentrations of HOCs in water. Separate short-term uptake and elimination experiments were performed, in clear water, as well as water containing sorbents. Zooplankton were exposed to two radiolabeled organochlorine compounds, hexachlorobenzene (HCBz) and dichlorodiphenyltrichloroethane (DDT). Zooplankton

body burdens were expected to decrease in the presence of sorbents, due to a decrease in freely dissolved chemical. However, suspended material that is very low in organic carbon, such as glacial clays, were expected to poorly sorb HOCs and not greatly reduce bioconcentration compared to clear water. Uptake due to particle ingestion was expected to be negligible. Body burdens were therefore expected to be a function of the freely dissolved chemical concentration. If uptake due to particle ingestion is significant, body burdens should be greater than those expected from the freely dissolved concentration in water. The importance of ingestion is expected to increase with chemical K_{OW}, because sorption is a function of K_{OW} (Boese *et al.* 1990). Elimination of HOCs was expected to increase with suspended particle concentration.

Methods

Approximately 60 L of glacial stream water was collected from Peyto Stream. The suspended solids were allowed to settle for at least 2 weeks, and the top 50 L was drawn off, producing a stock solution with a glacial solids concentration of about 2000 mg L^{-1}. Aliquots of the stock solution were subjected to particle size analysis on a Micromeritics Sedigraph 5100 and for organic carbon determination. Percent loss on ignition (%LOI) was determined by weight difference before and after combustion of dried sediments overnight at 500 °C, and converted to percent organic carbon (%OC) using an empirical relationship developed by Håkansson and Jansson (1983):

$$\%OC = 0.48 \times (\%LOI) - 0.73 \qquad (4\text{-}1)$$

The glacial solids had an organic carbon content of 1.3 ± 0.1%. About 95% of the particles were less than 25 μm in diameter, and 5% were less than 1 μm in diameter.

Zooplankton were collected from Bow lake using a large plankton net. They were then placed in a plastic bucket and kept on ice for transport back to the laboratory. Experiments were conducted at 6.0 ± 0.1 °C in a temperature controlled room. Zooplankton were allowed to acclimatize to the 6 °C laboratory for about 24 h before being used in experiments.

The exposure chambers were 250-mL clear glass jars with aluminum foil-lined lids. Each trial consisted of triplicate jars containing clear water, DOC (Aldrich humic acid, 1.5 mg DOC L^{-1}), and high (1000 mg L^{-1}) and low (100 mg L^{-1}) concentrations of glacial solids. Experiments were also periodically conducted with heat-killed zooplankton in clear water to examine non-respiratory uptake, and with zooplankton in water containing 100 mg L^{-1} *Chlorella* powder to determine uptake in the presence of a digestible sorptive agent. The organic carbon content of the *Chlorella* powder was 29%, determined in the same manner as the glacial particles.

Radiolabeled chemicals were obtained from Sigma Chemical Co. Reported radiochemical purity was greater than 98%, and the compounds were used without further purification. ^{14}C-DDT (specific activity 12.7 mCi $mmol^{-1}$) or ^{14}C-HCBz (specific activity 15.9 mCi $mmol^{-1}$) in acetone was added to 200 mL of water in each jar and allowed to equilibrate overnight. The presence of small amounts of acetone (10 µL in 200 mL water) is not expected to affect uptake kinetics (Landrum 1983). Spiking concentrations (0.42 ng mL^{-1}

for HCBz, 0.54 ng mL^{-1} for DDT) were approximately an order of magnitude below the water solubility of the chemical at 25°C (Suntio *et al.* 1988; Mackay *et al.* 1992).

The experimental procedure was similar to that of Landrum (1982). At the beginning of the experiment (t = 0), ten adult zooplankton (males and non-gravid females) were placed in each jar. Organisms were not fed during the experiments. At 2 and 4 h for July experiments, and 2, 4 and 6 h for August and September experiments, a 10-mL water sample was taken from each jar, placed in a scintillation vial and mixed with 10 mL of scintillation cocktail (ACS, Amersham). Immediately after the water sample was taken, the zooplankton were removed from each jar with a 190 μm Nitex mesh screen, rinsed with distilled water, placed in a scintillation vial, and scintillation cocktail was added. The zooplankton samples were stored for at least 2 d to allow the cocktail to extract the radiolabeled chemicals (Landrum 1988). Samples were then counted on a Beckman 6500 liquid scintillation counter with automatic quench correction. Separate jars were used for each replicate at each time point, and the water in the jars was not aerated or replaced during the uptake experiments.

Average organism weight and lipid content were determined separately using subsamples of the same zooplankton used in the uptake experiments. Groups of several hundred zooplankton were counted, then freeze-dried to avoid weighing errors associated with zooplankton drying out or having water caught in their numerous appendages and antennae. The freeze-dried sample was weighed and an average weight per organism calculated. Lipid was determined gravimetrically by grinding the sample with hexane

(Grussendorf *et al.* 1970), centrifuging to remove particulates, and evaporating the extract to constant weight. In September, an attempt was made to weigh the zooplankton in the uptake experiments directly. No freeze-drying losses were observed for DDT, but samples from the September HCBz experiments contained almost no ^{14}C activity after freeze-drying, presumably because the much higher vapour pressure of HCBz resulted in losses during freeze-drying. The September HCBz experiments were therefore not included.

For the elimination experiments, approximately 300 zooplankton were exposed to each radiolabeled chemical in clear water for 4 h, then divided equally among the four unspiked treatments: clear water, water containing algae, and water containing high or low concentrations of glacial particulate matter. Samples of ten zooplankton were removed at 0, 12, 24 and 48 h for HCBz and 0, 24, 48 and 72 h for DDT. The zooplankton were rinsed with distilled water, placed in a scintillation vial, mixed with cocktail and counted.

Data Analysis

Data were incorporated into a single-compartment model (Branson *et al.* 1975), where the organism is the compartment, and the concentration in water is assumed to be constant (i.e. not change with time):

$$\frac{dC_B}{dt} = k_1 C_W - k_2 C_B \qquad (4\text{-}2)$$

where C are chemical concentrations and k are first-order rate constants, t is time, and the subscripts B and W refer to the organism and water respectively. The elimination rate

constant k_2 has units of time^{-1}, while the uptake rate constant k_1 is more properly called a clearance because it has units of volume mass^{-1} time^{-1} rather than time^{-1}. It can be viewed as the volume of water cleared of chemical per unit organism mass per unit time (Stehly *et al.* 1990). Note that C_W is the freely dissolved chemical concentration in water, and does not include chemical bound to sorbents.

The uptake rate k_1 was determined in clear water during the initial linear uptake phase, where negligible elimination can be assumed ($k_2 = 0$). Upon rearrangement, Equation 4-2 reduces to

$$dC_B = k_1 C_W dt . \qquad (4\text{-}3)$$

C_B was plotted against ($C_W \times$ time) and a linear least-squares regression with a slope of k_1 was fit to the data. The origin was included as a data point. Slopes of regression lines were compared, and differences of intercepts from zero were determined using Student's *t*-tests ($p = 0.05$).

For treatments containing sorbents, uptake from particle ingestion was assumed to be negligible, with decreased uptake rates due to a reduction in dissolved chemical concentration rather than a change in k_1, i.e. k_1 is constant for all treatments. C_B was plotted against time and a linear least-squares regression with a slope of k_1C_W was fit to the data. The origin was included as a data point. C_W was then determined by dividing the slope by k_1 (determined in clear water). The difference between C_W and the total (dissolved and bound) concentration yielded the bound fraction, and this was compared to independent experimental measurements of sorption by batch sorption and sparging

(Chapter 3 of this thesis), as well as to empirical relationships between K_{OW} and organic carbon normalized sorption (Karickhoff *et al.* 1979; Schwarzenbach & Westall 1981). If calculations of the bound fraction are similar to independent measurements, then the assumption of negligible uptake from ingestion is valid.

Elimination of the chemical in clean water is assumed to be proportional to the concentration in the organism, and follow an exponential decay curve (Bruggeman *et al.* 1981):

$$\frac{dC_B}{dt} = -k_2 C_{B0} \qquad (4\text{-}4)$$

where C_{B0} is the contaminant concentration in the organism after a 4 h exposure period. Upon integration and rearrangement, Equation 4-4 becomes

$$\ln C_{B0} - \ln C_B = k_2 t . \qquad (4\text{-}5)$$

($\ln C_{B0} - \ln C_B$) was plotted against time and a linear least-squares regression with a slope of k_2 was fit to the data. The origin was included as a data point. Slopes of regression lines were compared, and differences of intercepts from zero were determined using Student's *t*-tests ($p = 0.05$).

A bioaccumulation factor (BAF) can be calculated by integrating Equation 4-2 to yield

$$C_B = \frac{k_1 C_W \left(1 - e^{-k_2 t}\right)}{k_2} \qquad (4\text{-}6)$$

The bioaccumulation factor, defined as C_B/C_W, approaches k_1/k_2 with increasing time. BAFs were calculated as the ratio of uptake and elimination rates in clear water and

compared to empirical relationships between BAF and K_{OW} (Mackay 1982; Oliver & Niimi 1983; Oliver & Niimi 1985; Meylan *et al.* 1999).

Results and Discussion

Mass balances generally exceeded 80%, except for HCBz experiments in August, which averaged less than 25%. In addition, zooplankton from September HCBz experiments contained almost no ^{14}C activity, presumably because of losses during freeze-drying. August and September HCBz experiments were therefore not included. Mass balances were lower for particulate treatments, indicating that some settling occurred before a water sample was taken. Settling of particles during the experiments may have decreased the amount of material ingested by the zooplankton. Jars were not rotated during the experiments due to leaking jar lids, but they were gently swirled at each collection time (every 2 h) to resuspend settled particles. *H. arcticus* may also forage in the settled particles, as they will eat algae powder off the bottom of an aquarium (personal communication, R. Vinebrook, University of Alberta, Edmonton, Canada).

In July and September, there were no significant differences in DDT uptake rates between clear water and the lower glacial concentration ($p < 0.05$, Figure 4-1). Where uptake rates in clear water were significantly different than glacial treatments, they were always higher, suggesting that the reduction in bioconcentration due to sorption of HOCs is greater than any increase in uptake due to particle ingestion (Figures 4-1 and 4-2). This is further supported by the extremely low uptake rates in the presence of algae, which are much more digestible than glacial particles, but also sorb HOCs strongly. Although DDT uptake rates in July for the lower glacial concentration were slightly higher than those in

clear water, suggesting that uptake by ingestion had occurred, the difference was not significant ($p > 0.05$). Low concentrations of glacial clays do not appear to significantly hinder uptake of HOCs by decreasing bioconcentration, or enhance it by sediment ingestion.

Uptake in the presence of DOC was always significantly lower than uptake in clear water for both chemicals ($p < 0.05$, Figures 4-1 and 4-2). However, Aldrich humic acid is known to strongly sorb HOCs, and should not be considered indicative of sorption in a system containing "natural" DOC (Malcolm & MacCarthy 1986; Gobas & Zhang 1994); it was included simply for comparison.

Zooplankton were not placed in clean water to purge their guts after the uptake experiments; therefore any ingested material was counted as part of their body burden. This may account for the slightly higher DDT concentrations in zooplankton for July experiments containing low concentrations of glacial particles. Because a full gut is about 10% of invertebrate weight (Brooke *et al.* 1996), the ingested particles would contribute considerably less than 10% to the total body burden due to the poor sorptive ability of the low organic glacial sediments compared to animal tissues. Others have also found that sediments in the gut contribute negligibly to total body burden (Oliver 1987; Lydy & Landrum 1993). In fact, assimilated chemical may be lost via diffusion during gut clearance (Mac & Schmitt 1992), resulting in underestimation of uptake rates. Purging in clean water may be slow because animals are not actively feeding, and purging with uncontaminated sediment may dilute the body burden or increase elimination rates.

Sorption to the carapace and passive diffusion into dead animals accounts for 6% and 40% of the uptake rates of HCBz and DDT, respectively (Figures 4-1 and 4-2). The higher value for DDT is probably due to its higher lipid solubility. Uptake of DDT does not appear to be highly diffusion-layer limited (Gobas *et al.* 1986).

The validity of the first-order single-compartment model relies on the assumptions that the concentration of chemical in water C_W does not change over the course of the experiment, that k_1 and k_2 (and therefore BAF) are independent of the chemical concentration, and that organism growth and chemical metabolism are negligible (Landrum *et al.* 1992b).

There were significant differences in aqueous HOC concentrations between the beginning and end of each experiment for the algae treatments for HCBz and the glacial and algae treatments for DDT. HOC concentrations in water were measured as total rather than freely dissolved chemical. It is likely that the test chemicals sorbed to the solid phases and settled to the bottom of the jar, resulting in an apparent decrease. However, the concentration of freely dissolved contaminant probably did not decrease during the experimental period because similar decreases were not seen in treatments that did not have solid phases. The extent of sorption to particles was related to chemical hydrophobicity: HCBz was not as strongly sorbed to particles as DDT due to its lower K_{OW}, resulting in an apparent decrease in aqueous HCBz concentrations only in the algae treatments.

A flow-through system is often recommended to maintain a constant concentration of contaminant in the water (ASTM, 1994). However, maintaining a constant aqueous concentration of the test chemical is difficult even in a flow-through system, particularly for very hydrophobic chemicals (McCarthy & Jimenez 1985; Bruner *et al.* 1994b). While a flow-through system would have been useful to keep particles suspended, a static exposure system effectively maintained a constant HOC concentration for the short duration of these experiments because the water volume was large enough to prevent depletion of the chemical by the organisms. Less than 10% of the total chemical in the water was accumulated by the zooplankton.

BAF independent of aqueous chemical concentration has generally been observed (Branson *et al.* 1975; Bishop & Maki 1980; Adams 1987; Thybaud & Caquet 1991), although BAF tends to be higher at high concentrations (Oliver & Niimi 1983; Oliver & Niimi 1985), probably due to saturation of elimination processes (Oliver & Niimi 1983; Barron 1990).

The assumption of no organism growth is a reasonable one considering the short time period of the experiments. The metabolism of these chemicals can also be assumed to be negligible over the short duration of the experiments, because both chemicals are highly persistent. If k_2 is derived from the measurement of radioactivity, it will include both the elimination of the parent chemical and its metabolites (Landrum *et al.* 1992b). However, Landrum (1988) did not observe biotransformation of benzo[*a*]pyrene in *Diporeia* over

14 days. Although biotransformation capability can vary greatly between species (Lee 1981), all ^{14}C activity was assumed to be parent chemical. The uptake experiments were shorter than 50% of one biological half-life (residence time of chemical within the organism), so the assumption that k_2 is negligible during the uptake experiments is probably also valid. The linearity of plots of C_B vs. time (R^2 generally greater than 0.9) also verifies that elimination during uptake was negligible. Intercepts of regression lines were not significantly different from zero ($p < 0.05$), and forcing regression lines through the origin did not significantly change the slope (Table 4-1).

There were temporal differences in both uptake and elimination rates. Temporal variability in HCBz uptake rates was unable to be determined: August and September experiments were discarded due to low mass balances. For DDT, uptake rates per unit lipid were highest in July (Figure 4-3). Elimination rates for both chemicals were also highest in July (Figure 4-4), although differences between months were only significant for HCBz ($p < 0.05$). Such differences may be due to the smaller size of the July zooplankton. Elimination rates of DDT and HCBz in zooplankton were several orders of magnitude higher than those reported in fish (Niimi 1987). Other investigators have found an inverse relationship between organism mass and uptake and elimination rates (Landrum 1988; Tarr *et al.* 1990; Bruner *et al.* 1994a). Sijm and van der Linde (1995) reported an inverse relationship between elimination rates and animal size, but suggested that the lipid content of the animal and the K_{OW} of the chemical were more important determinants of elimination rates. Similarly, Adams (1987) found that elimination is inversely related to lipid content. July zooplankton were the smallest and contained the

least lipid, suggesting that both organism size and lipid content determine elimination rates.

Higher uptake rates in smaller animals may be a result of higher surface area to volume ratios and higher rates of respiration per unit of mass (McLeese *et al.* 1980; Landrum & Stubblefield 1991). Small aquatic invertebrates such as zooplankton obtain oxygen through body surfaces as well as respiratory structures, and exchange of HOCs may occur by the same route. Surface area to volume ratio may therefore be an important determinant of uptake rates. Landrum and Stubblefield (1991) found that uptake rates for chemicals of moderate hydrophobicity were better described by surface area rather than by mass-based units. Barron *et al.* (1990) also suggested that elimination rates should be normalized to body size or surface area. The surface area of the organisms was estimated by assuming that the organism was a sphere with a density of 1 g mL^{-1} (Landrum & Stubblefield 1991). Although this does not give an accurate surface area, it is proportional to the true surface area. Normalizing uptake rates to lipid content and surface area to mass ratio reduced the variability among months (Figure 4-3).

Generally, there were no significant differences in elimination rates between treatments for either chemical ($p < 0.05$). Significant differences occurred between the high glacial and algae treatments in July for DDT, and between the high and low glacial treatments in August for HCBz. However, no consistent pattern of increased elimination with increased exposure to solids was seen, suggesting that ingestion of uncontaminated material does not increase elimination rates.

Uptake and elimination rates (and therefore BAF) appear to be related to K_{OW}. Other researchers have established linear relationships between bioconcentration factors (BCF) and K_{OW} (Mackay 1982; Meylan *et al.* 1999) and between k_2 and K_{OW} (Hawker & Connell 1985; Hawker & Connell 1986). BCFs derived from these relationships compare favorably with the experimental BAFs of this study (Table 4-4). The strong relationship between BAF and K_{OW} appears to be due mainly to the similarly strong relationship of k_2 (rather than k_1) with K_{OW} (Bruggeman *et al.* 1981; Hawker & Connell 1985): HCBz elimination rates were significantly higher in all months than those of DDT. Empirical relationships between K_{OW} and k_2 are considerably more variable: those derived from experiments using fish are two orders of magnitude lower than those derived from daphnid experiments (Hawker & Connell 1985; Hawker & Connell 1986). As discussed earlier, these differences are probably due to differences in organism size. BAFs derived from experiments using smaller organisms are similar to those of larger animals, suggesting that the effect of organism size on uptake and elimination rates tends to cancel out.

Lipid-normalized BAFs were slightly higher than the K_{OW} of the chemicals. This has also been found elsewhere (Gobas *et al.* 1991; Bruner *et al.* 1994a), and suggests that organic carbon pools other than lipid can store HOCs (Swackhamer & Skoglund 1993), or that octanol is not a perfect surrogate for lipid (Barron 1990). It has been suggested that phytoplankton BAFs be normalized to organic carbon rather than lipid content (Karickhoff 1984; Skoglund & Swackhamer 1999).

Calculation of the bound fraction from uptake rates in the DOC treatments agreed well with independent measurements of sorption, while no consistent pattern was seen with the glacial treatments (Tables 4-3 and 4-4). There was generally a relationship between the fraction bound and K_{OW}, with a greater fraction of DDT sorbing than HCBz. For DDT, the calculated bound fraction was lower than independent measurements (Table 4-3). This apparent decrease may be due to additional uptake by particle ingestion. However, for HCBz the calculated bound fraction in the low glacial concentration was higher than independent measurements, suggesting the opposite trend (Table 4-4). The calculated bound HCBz fraction for the high glacial concentrations agreed well with independent measurements, suggesting that uptake by ingestion did not occur. The empirical relationships tended to overestimate the bound fraction compared to uptake experiments. The relationship of Schwarzenbach and Westall (1981) was better at predicting the fraction bound to glacial particles, presumably because it was derived using low organic carbon sediments. The relationship derived by Karickhoff *et al.* (1979), better predicted the fraction bound to DOC and algae.

Conclusions

Our experiments indicate that direct uptake from water (i.e. bioconcentration) rather than particle ingestion is the dominant uptake route of HOCs by *H. arcticus*. Low concentrations of glacial clays do not appear to significantly hinder uptake by decreasing bioconcentration, or enhance it by particle ingestion. Where zooplankton HOC concentrations in clear water were significantly different than glacial treatments, they were always higher, suggesting that the reduction in bioconcentration due to sorption of

HOCs is greater than any increase in uptake due to particle ingestion. This is further supported by the extremely low uptake rates in the presence of algae, which is much more digestible than glacial particles, but also sorbs HOCs strongly. Uptake in the presence of DOC was always significantly lower than uptake in clear water. Temporal differences in uptake and elimination rates may have been due to differences in zooplankton size and lipid content. The presence of particles or algae did not change elimination rates. Calculation of sorption using uptake rates was more successful for water containing DOC than for water containing glacial particles.

Table 4-1. Uptake rate constants (mL g^{-1} h^{-1}, dry weight) determined in clear water (mean ± 1 SE).

Chemical	Month	Origin included			Origin forced	
		k_1 (mL g^{-1} h^{-1})	Intercept	R^2	k_1 (mL g^{-1} h^{-1})	R^2
DDT	July	6200 ± 600 (n = 9)	280 ± 700	0.937	6300 ± 440 (n = 6)	0.976
	August	9300 ± 330 (n = 12)	610 ± 440	0.988	9600 ± 240 (n = 9)	0.995
	September	5500 ± 340 (n = 12)	920 ± 590	0.963	5900 ± 250 (n = 9)	0.986
HCBz	July	5300 ± 220 (n = 9)	260 ± 220	0.988	5500 ± 180 (n = 6)	0.995

Table 4-2. Comparison of experimental BAFs with empirical relationships.

	DDT	HCBz
This study, July	4.95	4.31
This study, August	5.49	NA[a]
This study, September	5.25	NA
Mackay (1982)	5.04	4.18
Oliver & Niimi (1983)	5.14	4.40
Oliver & Niimi (1985)	5.55	4.72
Meylan *et al.* (1999)	5.08	4.34

[a]NA: not analyzed; experiments discarded due to low mass balances.

Table 4-3. Percentage of DDT bound to sorbents (mean ± 1 SD, n = 3).

Sorbent	This study	Sparging	Batch sorption	Empirical[a]	Empirical[b]
Glacial (100 mg L^{-1})	5 ± 12	14	5	65	14
Glacial (1000 mg L^{-1})	27 ± 14	63	37	95	61
DOC (1.5 mg L^{-1})	54 ± 8	60	not tested	68	15
Algae (100 mg L^{-1})	88 ± 11	not tested	not tested	98	80

[a]Karickhoff *et al.* (1979)
[b]Schwarzenbach & Westall (1981)

Table 4-4. Percentage of HCBz bound to sorbents (July only).

Sorbent	This study	Sparging	Batch sorption	Empirical[a]	Empirical[b]
Glacial (100 mg L^{-1})	20	2	2	21	4
Glacial (1000 mg L^{-1})	16	19	15	72	27
DOC (1.5 mg L^{-1})	35	31	not tested	23	4
Algae (100 mg L^{-1})	80	not tested	not tested	87	49

[a]Karickhoff *et al.* (1979)
[b]Schwarzenbach & Westall (1981)

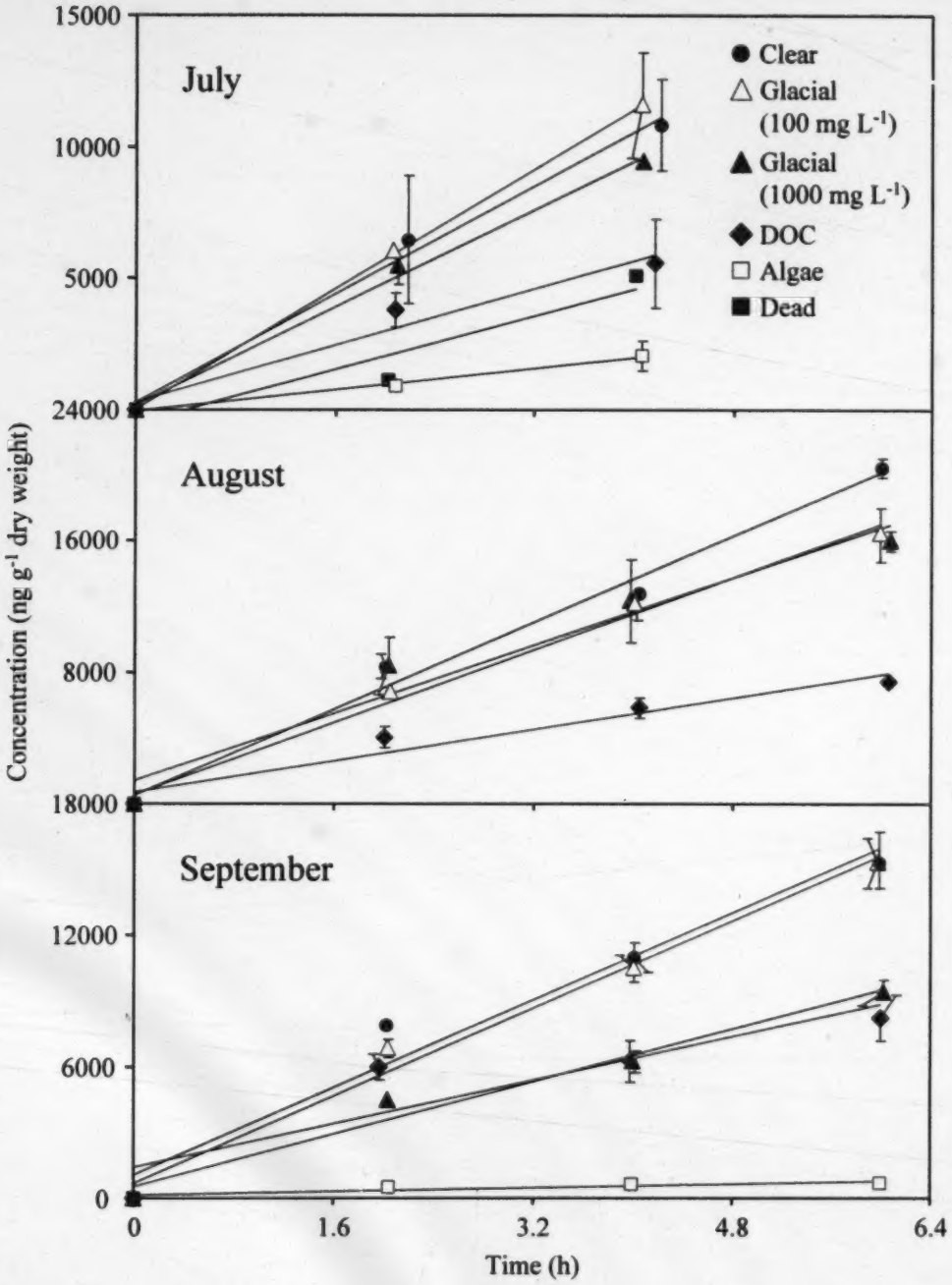

Figure 4-1. Uptake of DDT by zooplankton from water containing various sorbents. Error bars are ±1 SE (n = 3).

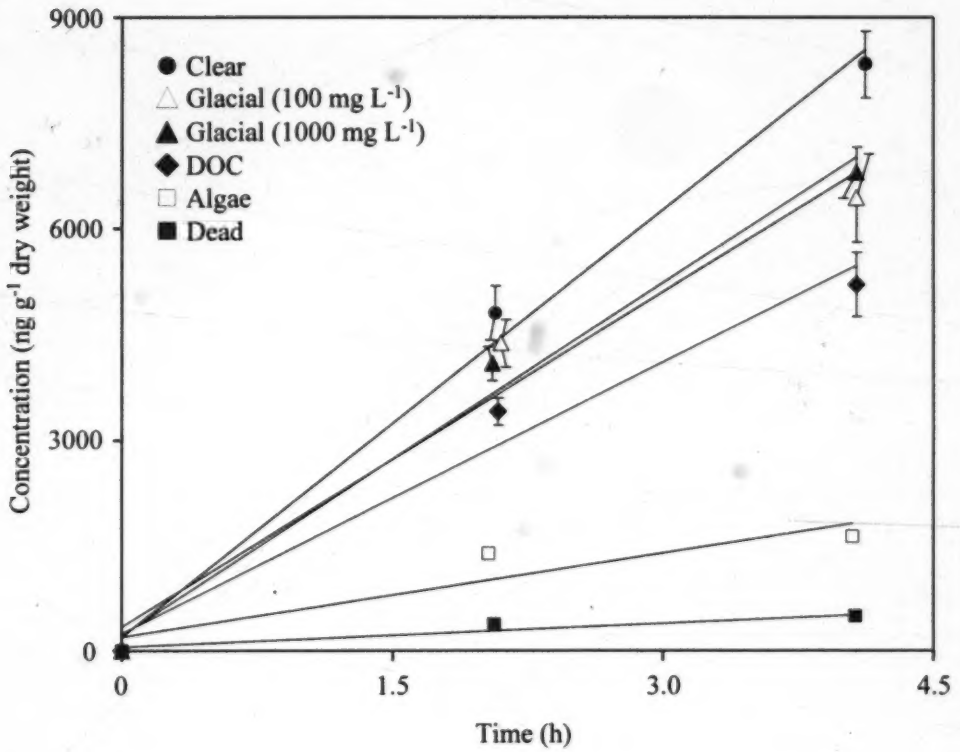

Figure 4-2. Uptake of HCBz by zooplankton from water containing various sorbents (July). Error bars are ±1 SE (n = 3).

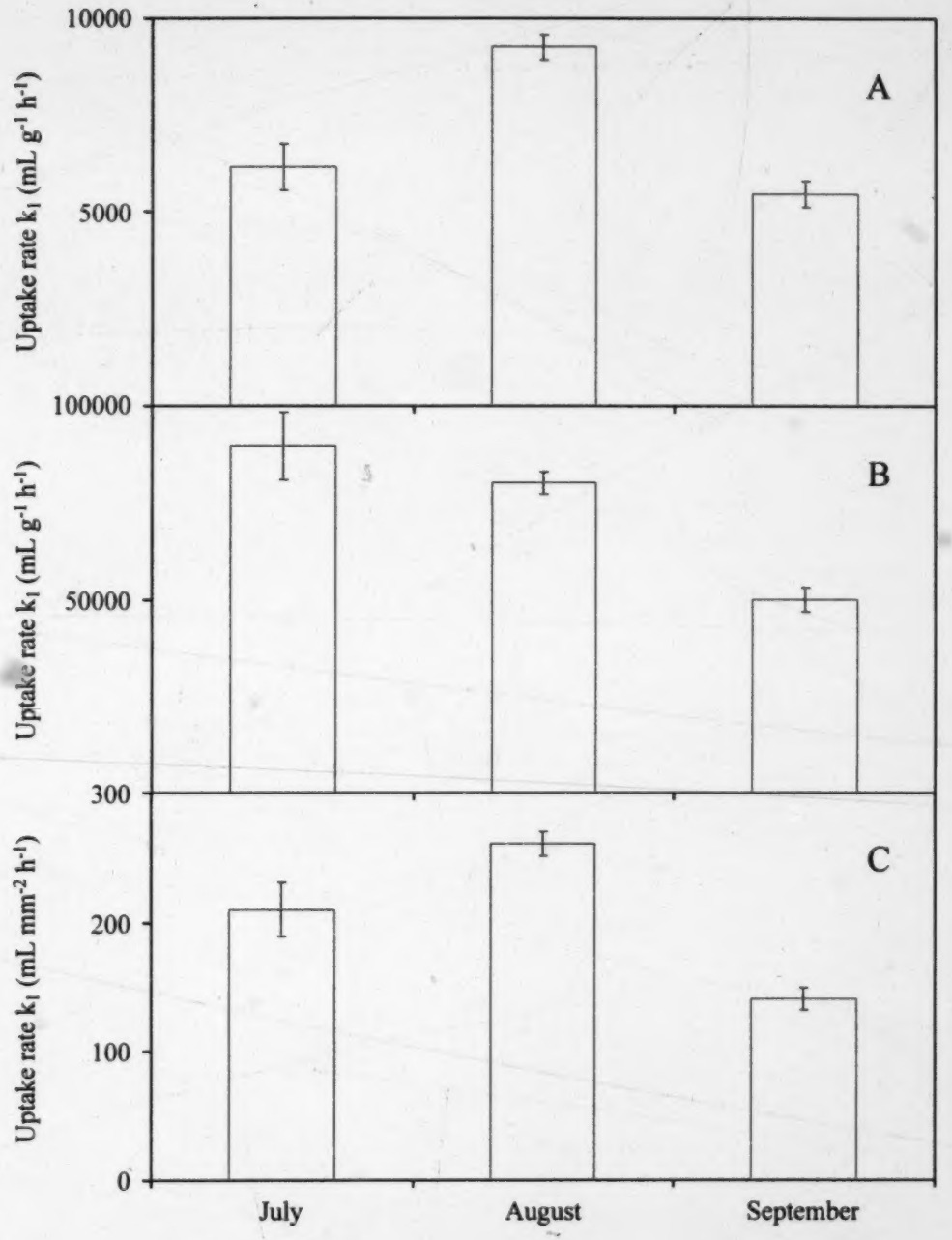

Figure 4-3. Temporal variability in DDT uptake rates, expressed as (A) per gram, (B) per gram of lipid, and (C) per mm^2. Error bars are ±1 SE (n = 9 for July, n = 12 for August and September).

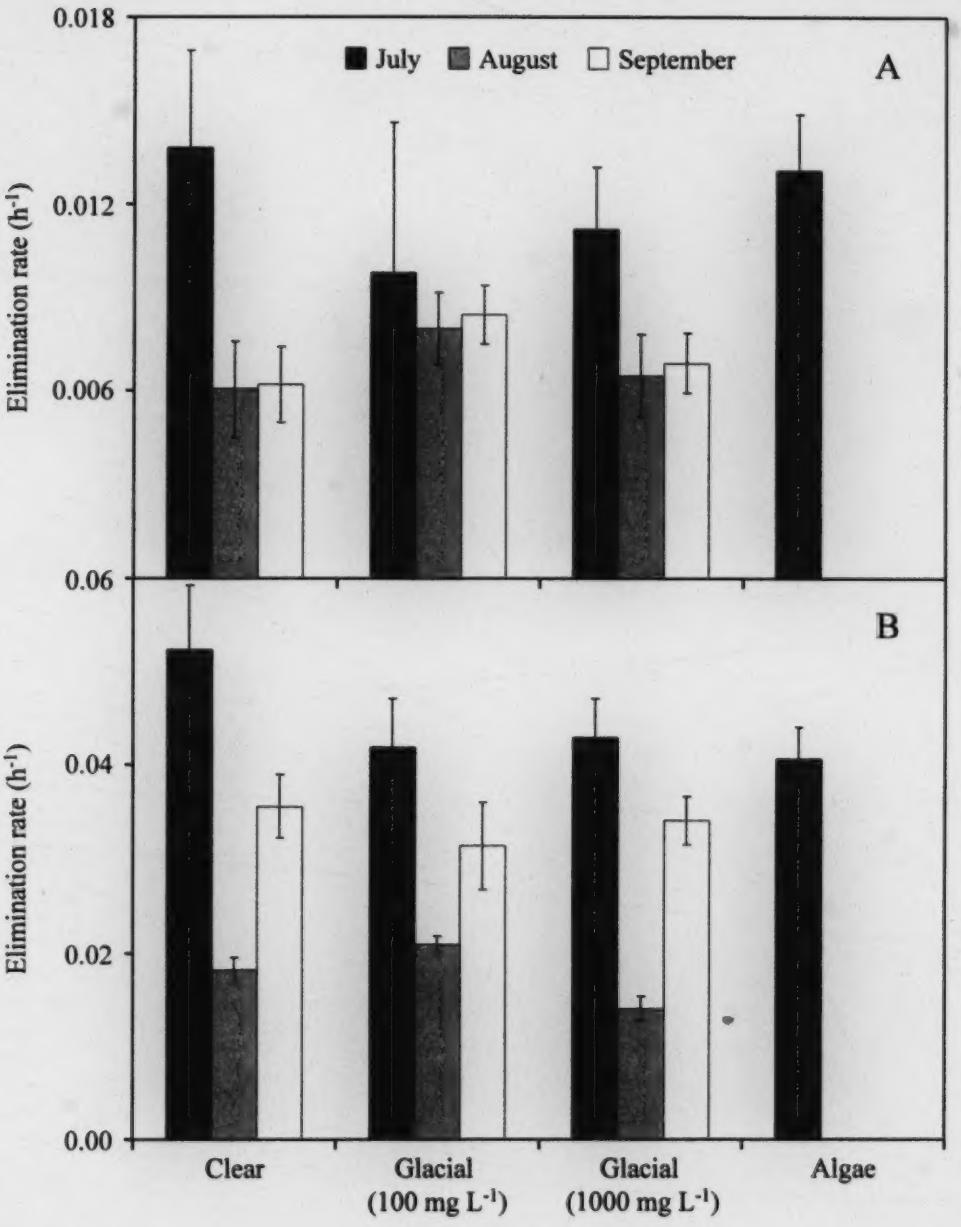

Figure 4-4. Temporal variability in elimination rates for (A) DDT and (B) HCBz. Error bars are ±1 SE (n = 9 for July, n = 12 for August and September).

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5 General Discussion and Conclusions

Ingestion of glacial clays does not appear to significantly enhance HOC uptake by zooplankton. However, the importance of dietary uptake depends on feeding rate, assimilation efficiency (which can vary with feeding rate), concentration in the food and food quality (Thomann 1989; Landrum *et al.* 1992), and these vary depending on the life stage of the organism. Wilhelm (1999) found that alpine *Gammarus* had a two-year life cycle, while those at lower elevations had a one-year life cycle. *Hesperodiaptomus arcticus* from Bow Lake may also have a life cycle longer than one year: zooplankton collected from Bow Lake in June of 1998 were much larger than those collected in the same period in 1999. The importance of particle ingestion may have been greater than these experiments suggest if zooplankton were sampled at a different point in their life history.

Annual differences may also have been due to differences in lake temperature. Temperature affects many variables that determine HOC fate, including volatilization rates, sorption dynamics, and physiological processes. Competing processes, such as HOC uptake and elimination rates, are often both highly temperature-dependent. HOC body burdens depend on the relative effect of temperature on each process (Barron 1990).

Equilibrium partitioning theory suggests that BAF, K_{OW} and K_{PW} will decrease with an increase in temperature. The activity of a chemical in an organic phase is usually very close to unity for nonpolar organic compounds (Schwarzenbach *et al.* 1993) and would not be expected to vary significantly with temperature. Changes in the distribution of a

chemical between organic and aqueous phases are due to changes in its aqueous activity (Karickhoff 1984; Perlinger & Eisenreich 1991), and the activity of a compound in water decreases with increasing temperature.

HOC concentrations in zooplankton are related to their lipid content (Clayton, Jr. *et al.* 1977), but there is disagreement on whether lipid content is an important determinant of HOC body burden in higher trophic levels. Large fish are thought to accumulate HOCs primarily through diet (Thomann 1989). Long food chains result in high HOC concentrations in these top predators in a process known as biomagnification. It is thought to occur because contaminants are not readily metabolized and are efficiently transferred from one trophic level to the next (Woodwell 1967).

The accurate determination of trophic position using stable isotopes of carbon and nitrogen has resulted in correlations with HOC concentrations (Kidd *et al.* 1995; Kucklick & Baker 1998). However, lipid content and organism size have also been correlated with trophic position (Rasmussen *et al.* 1990; Kidd *et al.* 1995). Although stable nitrogen isotopes accurately depict differences in diet (and therefore trophic position) between organisms, they do not correlate well with HOC concentrations unless there is also an increase in organism lipid with trophic level (Olsson *et al.* 2000). This suggests that variables other than trophic position determine HOC body burdens.

Food chain models often use organism mass as an indicator of trophic position (Norstrom *et al.* 1976; Thomann 1981). In allometric models, individual mass increases and total

biomass decreases at each trophic level, but all organisms feed from a hypothetical common food pool (Griesbach *et al.* 1982). The similarity in output between the two models suggests that HOC body burdens are more related to organism size than trophic position.

In small organisms such as phytoplankton, the large ratio of surface area to volume results in rapid equilibration with environmental water concentrations. As an organism increases in size, its surface area to volume ratio decreases, and the ability to exchange chemicals with the surrounding water is reduced. Hydrophobic chemicals are often transported away from exchange sites to lipid compartments and sequestered, where they are not readily metabolized or released (Geyer *et al.* 1993). If a large fish is at equilibrium with the surrounding water, and the water concentration decreases, it will take much longer for equilibrium to be re-established in large fish than the much smaller plankton.

To determine which of these variables (trophic level, lipid content or size) control HOC concentrations, systems where a correlation between the variables does not exist need to be found and thoroughly examined. Examples include Bow Lake, where zooplankton are much higher in lipid than all other trophic levels, and aquatic systems where prey are larger than predators. Other research on Bow Lake suggests that HOC concentrations are related to lipid content rather than trophic position (Campbell *et al.* 2000).

Because HOCs levels are usually expressed as concentrations, organism growth tends to decrease HOC concentrations. Conversely, fasting or starvation tends to increase concentrations (Polischuk *et al.* 1995). Bull trout (*Salvelinus confluentus*) from Harrison Lake, a small alpine lake in the Canadian Rocky Mountains, have enough food in the spring to increase in length, but do not receive enough food in the rest of the summer to increase their mass in proportion to the earlier length increases (Wilhelm *et al.* 1999). The result is long skinny fish. HOC concentrations in fish from Harrison Lake may be high due to very low (possibly negative) growth rates. Further study of unusual aquatic systems, such as Bow and Harrison Lakes, is required to critically examine the universality of processes that govern HOC dynamics.

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Appendix 1: Derivation of Equation 3-4

Mass balance: $M_T = M_W + M_P$ A-1

$$C_T V_T = C_W V_W + C_P m$$

Assume that the volume of particles is negligible: $V_T = V_W$

$$C_T V_W = C_W V_W + C_P m$$

$$S = \frac{m}{V_W}$$

$$C_T = C_W + C_P S \quad \text{A-2}$$

$$\frac{C_T}{C_W} = 1 + \frac{C_P S}{C_W}$$

$$K_{PW} = \frac{C_P}{C_W}$$

$$\frac{C_T}{C_W} = 1 + K_{PW} S$$

$$C_W = \frac{C_T}{1 + K_{PW} S} \quad \text{A-3}$$

Fugacity in air: $f_A = xP_T$ A-4

Ideal gas law: $P_T V = nRT$ A-5

Combining Equations A-4 and A-5

$$f_A = \frac{xnRT}{V}$$

$$C_A = \frac{xn}{V}$$

$$f_A = C_A RT \quad \text{A-7}$$

Fugacity in water: $f_W = C_W H$ A-8

At equilibrium, $f_A = f_W$

$$C_A RT = C_W H$$

$$K_{AW} = \frac{C_A}{C_W} = \frac{H}{RT} \quad \text{A-9}$$

$$K_{AW}' = \frac{C_A}{C_T} = \frac{K_{AW}}{1 + K_{PW} S} \quad \text{A-10}$$

$$K_{PW} = \left(\frac{K_{AW}}{K_{AW}'} - 1 \right) \frac{1}{S} = \frac{K_{AW} - K_{AW}'}{K_{AW}' S} \quad \text{A-11}$$

Symbols

C	chemical concentration
f	fugacity
H	Henry's law constant
K_{AW}	air-water partition coefficient
K_{AW}'	apparent air-water partition coefficient in the presence of particles
K_{PW}	particle-water partition coefficient
m	mass of particles
M	mass of chemical
n	total amount of air and chemical
P_T	total system pressure
R	gas constant (8.314 Pa m^3/mol K)
S	particle concentration
T	temperature (K)
V	volume
x	mole fraction of chemical

Subscripts

A	air
P	particles
T	total
W	water

Appendix 2: HOC Concentrations in Environmental Media

Sample	Units	Notes	% Recov. PCB 30	% Recov. OCN
Bow PUF (18 Jun 1999)	pg/L		43.9	204.5
Bow PUF (08 Jul 1999)	pg/L		79.1	309.9
Bow PUF (29 Jul 1999)	pg/L		82.8	315.3
Bow PUF (17 Sep 1999)	pg/L		76.4	293.8
Peyto PUF (17 Jun 1999)	pg/L		62.2	246.7
Peyto PUF (07 Jul 1999)	pg/L		69.2	276.7
Peyto PUF (28 Jul 1999)	pg/L		60.8	272.1
Peyto PUF (16 Sep 1999)	pg/L		82.4	375.9
PUF blank, July 1999	pg/L	F1 evaporated to dryness	81.4	304.6
PUF blank, September 1999	pg/L	used to blank correct PUF samples	78.5	420.5
Bow 1 SPMD, triolein, June 1999	ng/g	Deployed 20 days, F3 not run	79.0	133.6
Bow 1 SPMD, almond oil, June 1999	ng/g	Deployed 20 days, F3 not run	84.1	73.8
Bow 2 SPMD, triolein, June 1999	ng/g	Deployed 20 days	82.2	88.7
Bow 2 SPMD, almond oil, June 1999	ng/g	Deployed 20 days, F3 not run	88.8	88.0
Bow 3 SPMD, triolein, June 1999	ng/g	Deployed 20 days, F3 not run	82.8	99.9
Bow 3 SPMD, almond oil, June 1999	ng/g	Deployed 20 days, F3 not run	86.9	81.6
Bow 1 SPMD, triolein, July 1999	ng/g	Deployed 21 days	85.9	84.1
Bow 1 SPMD, almond oil, July 1999	ng/g	Deployed 21 days	88.7	75.0
Bow 2 SPMD, triolein, July 1999	ng/g	Deployed 21 days, F3 not run	82.6	137.4
Bow 2 SPMD, almond oil, July 1999	ng/g	Deployed 21 days	85.1	84.5
Bow 3 SPMD, triolein, July 1999	ng/g	Deployed 21 days	91.2	96.6
Bow 3 SPMD, almond oil, July 1999	ng/g	Deployed 21 days, F3 not run	88.3	87.8
Bow 1 SPMD, triolein, August 1999	ng/g	Deployed 50 days, Florisiled twice, RTs way off in F3	77.1	145.2
Bow 1 SPMD, almond oil, August 1999	ng/g	Deployed 50 days, F3 evaporated to dryness	77.4	132.6
Bow 2 SPMD, triolein, August 1999	ng/g	Deployed 50 days, F3 not run	81.7	99.2
Bow 2 SPMD, almond oil, August 1999	ng/g	Deployed 50 days, F1 very dirty, F3 not run	86.1	70.5
Bow 3 SPMD, triolein, August 1999	ng/g	Deployed 50 days, F3 not run	84.5	101.3
Bow 3 SPMD, almond oil, August 1999	ng/g	Deployed 50 days, F3 not run	84.2	80.2
Peyto 1 SPMD, triolein, June 1999	ng/g	Deployed 20 days, F3 not run	82.4	175.8
Peyto 2 SPMD, triolein, June 1999	ng/g	Deployed 20 days	84.1	82.9
Peyto 1 SPMD, triolein, July 1999	ng/g	Deployed 21 days, F3 not run	84.4	123.7
Peyto 2 SPMD, triolein, July 1999	ng/g	Deployed 21 days, F3 not run	89.2	95.8

		PCBs												
Sample	Units	7	6	8/5	19	18	27/ 24	16/ 32	26	25	31	28	33	22
Bow PUF (18 Jun 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.2	2.4	ND	ND
Bow PUF (08 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.3	0.8	ND	ND
Bow PUF (29 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow PUF (17 Sep 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.1	2.3	ND	ND
Peyto PUF (17 Jun 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.1	17.8	6.4	ND
Peyto PUF (07 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.1	0.8	7.8	ND
Peyto PUF (28 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto PUF (16 Sep 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PUF blank, July 1999	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	21.8	30.7	10.5	ND
PUF blank, September 1999	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.7	13.0	ND	ND
Bow 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.09	0.04	ND	ND
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	1.53	1.05	ND	ND	0.15	0.22	ND	0.13	ND	0.04	0.10	ND
Bow 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	0.00	0.02	ND	ND	0.34	ND	ND	ND
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	0.80	ND	ND	ND	0.02	0.23	ND	ND	0.00	ND	0.04	ND
Bow 3 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	0.05	0.02	ND	0.00	0.27	ND	ND	ND
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	1.03	0.91	ND	ND	0.09	0.22	ND	0.03	0.07	0.10	0.17	ND
Bow 1 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.05	ND	ND	0.40	0.02	ND	0.34
Bow 1 SPMD, almond oil, July 1999	ng/g	ND	0.48	ND	ND	ND	ND	0.15	ND	ND	0.09	0.01	0.02	ND
Bow 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.27	0.07	0.03	ND
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	0.00	0.17	ND	ND	0.03	ND	ND	ND
Bow 3 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.02	ND	ND	0.27	0.06	ND	ND
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	0.61	ND	ND	ND	0.05	0.20	ND	ND	ND	ND	0.02	ND
Bow 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.22	ND	ND	ND
Bow 1 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	0.13	ND	ND	0.15	0.13	0.07	0.15	ND
Bow 2 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	0.02	ND	ND	0.16	0.23	0.08	ND	ND
Bow 2 SPMD, almond oil, August 1999	ng/g	ND	1.80	0.78	ND	ND	0.05	ND	ND	0.13	ND	ND	0.14	ND
Bow 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05	0.05	ND	ND
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	0.99	ND	ND	ND	0.18	ND	0.10	0.19	0.03	0.24	ND	ND
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	0.02	ND	ND	0.48	0.12	ND	ND
Peyto 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	0.00	0.02	ND	ND	0.36	0.08	ND	ND
Peyto 1 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.00	ND	ND	0.13	ND	ND	ND
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	0.13	0.03	ND	0.01	0.07	ND	ND	ND

		PCBs													
Sample	Units	45	46	52	49	47	48	44	42	64	40	74	70/ 76	66/ 95	60/ 56
Bow PUF (18 Jun 1999)	pg/L	ND	ND	ND	23.1	ND	ND	52.2	17.4	ND	ND	5.9	15.0	18.9	ND
Bow PUF (08 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	9.4	ND	ND	ND	2.1	ND	ND	ND
Bow PUF (29 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow PUF (17 Sep 1999)	pg/L	ND	ND	ND	ND	ND	ND	5.4	ND	ND	ND	1.8	7.0	7.6	ND
Peyto PUF (17 Jun 1999)	pg/L	ND	ND	ND	16.5	ND	ND	35.6	18.5	ND	ND	5.1	14.9	14.8	ND
Peyto PUF (07 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	13.6	1.0	ND	ND	4.9	ND	ND	ND
Peyto PUF (28 Jul 1999)	pg/L	ND	ND	60.8	16.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto PUF (16 Sep 1999)	pg/L	ND	ND	ND	ND	ND	ND	5.7	ND	ND	ND	ND	ND	ND	ND
PUF blank, July 1999	pg/L	ND	ND	ND	ND	ND	ND	23.8	8.5	10.1	ND	30.6	97.1	140.2	ND
PUF blank, September 1999	pg/L	ND	ND	ND	ND	ND	ND	ND	6.5	ND	ND	3.3	21.0	22.7	ND
Bow 1 SPMD, triolein, June 1999	ng/g	ND	ND	0.14	0.07	ND	ND	ND	0.02	ND	ND	0.08	0.12	0.37	ND
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.04	ND	ND	0.02	0.11	ND
Bow 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	0.16	ND	ND	0.06	0.02	ND	ND	0.07	0.10	0.11	0.14
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	ND	0.21	ND	ND	ND	ND	ND	0.05	ND	0.02	0.11	0.13	ND
Bow 3 SPMD, triolein, June 1999	ng/g	ND	ND	0.15	0.12	ND	ND	ND	ND	0.03	ND	0.03	0.13	0.25	ND
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05	ND
Bow 1 SPMD, triolein, July 1999	ng/g	ND	ND	0.34	0.24	0.10	0.09	0.02	0.04	0.06	ND	0.04	0.11	0.15	ND
Bow 1 SPMD, almond oil, July 1999	ng/g	ND	ND	0.37	0.08	ND	ND	0.13	0.04	0.05	ND	0.00	ND	ND	ND
Bow 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	0.16	ND	ND	ND	0.07	0.02	ND	0.06	0.08	0.29	ND
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	ND	0.18	0.08	ND	ND	0.13	0.04	0.03	ND	ND	ND	0.03	ND
Bow 3 SPMD, triolein, July 1999	ng/g	ND	ND	0.02	0.24	0.11	ND	0.01	0.04	0.03	ND	ND	ND	0.07	ND
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.06	ND	0.01	0.04	0.13	ND
Bow 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	0.26	ND	ND	ND	0.08	0.01	ND	0.05	0.16	0.18	ND
Bow 1 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	0.21	ND	ND	ND	0.06	0.06	ND	0.03	0.04	0.16	ND
Bow 2 SPMD, triolein, August 1999	ng/g	ND	ND	0.18	0.25	0.12	ND	ND	ND	0.02	ND	0.03	0.11	0.22	ND
Bow 2 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, triolein, August 1999	ng/g	ND	ND	0.09	0.20	ND	ND	ND	0.01	0.04	ND	0.03	0.16	0.30	ND
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.07	ND	ND	0.06	0.19	ND
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	ND	0.08	0.18	ND	ND	ND	0.05	0.06	ND	0.05	0.20	0.58	ND
Peyto 2 SPMD, triolein, June 1999	ng/g	ND	ND	0.08	0.14	0.07	ND	0.03	0.06	0.01	ND	0.05	0.10	0.09	ND
Peyto 1 SPMD, triolein, July 1999	ng/g	ND	ND	0.11	0.20	ND	ND	0.01	0.12	0.03	ND	0.00	ND	0.19	ND
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	0.18	ND	ND	ND	ND	0.00	ND	ND	0.02	0.20	ND

		PCBs												
Sample	Units	84	101/89	99	97	87	136	110	82/151	135/144	149	118	134	114
Bow PUF (18 Jun 1999)	pg/L	ND	1.0	ND	3.6	11.2	ND	ND	ND	ND	ND	ND	ND	ND
Bow PUF (08 Jul 1999)	pg/L	2.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow PUF (29 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow PUF (17 Sep 1999)	pg/L	ND	13.2	ND	8.1	12.6	ND	20.9	5.7	ND	15.7	48.9	1.9	ND
Peyto PUF (17 Jun 1999)	pg/L	ND	4.3	ND	1.2	4.4	ND	45.4	ND	ND	ND	53.5	ND	ND
Peyto PUF (07 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	12.1	ND	5.0	6.2	ND	ND
Peyto PUF (28 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	22.5	ND	ND	ND	ND
Peyto PUF (16 Sep 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PUF blank, July 1999	pg/L	11.1	175.7	113.7	72.3	117.5	16.9	283.6	63.7	ND	189.0	391.5	26.3	ND
PUF blank, September 1999	pg/L	ND	22.2	ND	7.6	10.9	ND	27.9	4.7	ND	37.6	34.1	2.7	ND
Bow 1 SPMD, triolein, June 1999	ng/g	ND	0.21	ND	ND	0.08	ND	0.23	ND	ND	ND	1.11	ND	ND
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	0.19	ND	0.17	0.06	ND	0.23	ND	ND	0.27	0.61	ND	ND
Bow 2 SPMD, triolein, June 1999	ng/g	ND	0.11	0.13	0.20	0.09	ND	0.06	ND	ND	0.04	0.77	ND	ND
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	0.11	ND	ND	0.01	ND	0.04	ND	ND	ND	0.96	ND	ND
Bow 3 SPMD, triolein, June 1999	ng/g	ND	0.18	ND	ND	ND	ND	0.11	ND	ND	ND	1.16	ND	ND
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	0.15	ND	0.15	0.08	ND	0.26	ND	ND	0.25	0.50	ND	ND
Bow 1 SPMD, triolein, July 1999	ng/g	0.14	0.20	0.14	0.11	0.14	ND	0.11	ND	ND	0.04	1.15	ND	ND
Bow 1 SPMD, almond oil, July 1999	ng/g	ND	0.17	0.10	0.08	0.01	ND	0.08	ND	ND	0.08	0.86	ND	ND
Bow 2 SPMD, triolein, July 1999	ng/g	0.12	0.16	ND	ND	ND	ND	0.09	ND	ND	ND	1.09	ND	ND
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	0.11	ND	0.06	0.05	ND	ND	ND	ND	ND	0.65	ND	ND
Bow 3 SPMD, triolein, July 1999	ng/g	0.15	0.13	ND	0.10	0.12	ND	0.05	ND	ND	0.00	1.08	ND	ND
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	0.18	ND	ND	0.05	ND	0.30	ND	ND	0.03	1.32	ND	ND
Bow 1 SPMD, triolein, August 1999	ng/g	0.11	0.45	ND	0.26	0.18	ND	0.67	0.14	ND	0.62	1.79	ND	ND
Bow 1 SPMD, almond oil, August 1999	ng/g	0.06	0.35	ND	0.23	0.06	ND	0.46	0.22	ND	0.42	1.48	ND	ND
Bow 2 SPMD, triolein, August 1999	ng/g	0.16	0.35	ND	0.19	ND	ND	0.41	ND	ND	0.20	1.53	ND	ND
Bow 2 SPMD, almond oil, August 1999	ng/g	ND	0.16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, triolein, August 1999	ng/g	0.17	0.39	ND	0.26	0.10	ND	0.42	ND	ND	0.17	1.55	ND	ND
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	0.26	ND	0.22	0.05	ND	0.27	ND	ND	0.12	1.27	ND	ND
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	0.31	ND	0.27	0.12	ND	0.18	ND	ND	ND	2.31	ND	ND
Peyto 2 SPMD, triolein, June 1999	ng/g	0.11	0.21	0.17	ND	0.08	ND	0.10	ND	ND	0.08	0.93	ND	ND
Peyto 1 SPMD, triolein, July 1999	ng/g	ND	0.99	0.33	0.36	0.17	ND	0.14	0.26	ND	0.43	2.92	ND	ND
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	0.24	ND	ND	0.10	ND	0.17	ND	ND	0.15	2.04	ND	ND

		PCBs													
Sample	Units	131	153	132	105	141	137	130/ 176	138	158	129	178	187	183	128
Bow PUF (18 Jun 1999)	pg/L	ND	ND	ND	0.6	ND	ND	ND	ND	2.7	1.5	ND	ND	ND	ND
Bow PUF (08 Jul 1999)	pg/L	ND	ND	ND	ND	ND	1.0	ND	ND	ND	ND	ND	ND	1.0	ND
Bow PUF (29 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow PUF (17 Sep 1999)	pg/L	ND	41.1	11.9	17.3	7.5	5.0	4.4	61.7	9.2	5.8	ND	17.3	5.1	12.6
Peyto PUF (17 Jun 1999)	pg/L	ND	0.9	1.0	2.6	0.3	ND	ND	ND	0.3	1.2	ND	ND	ND	ND
Peyto PUF (07 Jul 1999)	pg/L	ND	ND	2.4	1.3	ND	0.3	ND	ND	ND	ND	ND	0.9	1.4	ND
Peyto PUF (28 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto PUF (16 Sep 1999)	pg/L	ND	ND	1.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PUF blank, July 1999	pg/L	21.5	255.0	84.0	174.7	49.7	37.4	40.3	391.7	62.6	37.0	ND	50.7	30.1	91.9
PUF blank, September 1999	pg/L	3.4	23.7	8.6	10.0	4.0	2.7	3.2	36.1	8.8	2.6	ND	2.9	1.5	7.4
Bow 1 SPMD, triolein, June 1999	ng/g	ND	0.16	ND	0.08	0.05	ND	ND	0.34	0.17	ND	ND	ND	ND	0.08
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	0.18	0.12	0.03	0.05	ND	ND	0.13	0.00	ND	ND	ND	ND	0.04
Bow 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND	0.05	ND	ND	0.05
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	0.09	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, triolein, June 1999	ng/g	ND	0.07	ND	0.09	ND	ND	ND	0.08	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	0.06	0.08	0.02	0.06	ND	ND	0.17	0.02	ND	ND	ND	ND	0.04
Bow 1 SPMD, triolein, July 1999	ng/g	ND	ND	0.06	ND	0.04	ND	ND	ND	ND	ND	ND	ND	ND	0.03
Bow 1 SPMD, almond oil, July 1999	ng/g	ND	0.01	0.04	ND	0.04	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Bow 2 SPMD, triolein, July 1999	ng/g	ND	0.06	0.13	ND	ND	ND	ND	0.09	0.14	ND	ND	ND	ND	0.05
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND	ND	ND	ND	0.00
Bow 3 SPMD, triolein, July 1999	ng/g	ND	ND	0.03	ND	ND	ND	ND	ND	ND	ND	0.05	ND	ND	ND
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	0.15	ND	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND	0.04
Bow 1 SPMD, triolein, August 1999	ng/g	ND	0.76	0.43	0.17	0.13	0.13	ND	0.80	0.22	ND	ND	0.27	0.11	0.15
Bow 1 SPMD, almond oil, August 1999	ng/g	ND	0.57	0.28	0.15	0.11	0.07	ND	0.58	0.08	ND	ND	0.19	0.06	0.11
Bow 2 SPMD, triolein, August 1999	ng/g	ND	0.26	0.29	0.07	0.05	0.09	ND	0.34	0.12	ND	ND	0.10	ND	0.09
Bow 2 SPMD, almond oil, August 1999	ng/g	ND	0.09	0.28	0.04	ND	ND	ND	0.12	0.01	ND	ND	ND	ND	0.03
Bow 3 SPMD, triolein, August 1999	ng/g	ND	0.25	0.25	0.04	0.05	0.07	ND	0.29	0.13	ND	ND	0.09	0.07	0.07
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	0.21	0.14	0.03	0.05	ND	ND	0.11	ND	ND	ND	0.08	ND	ND
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	0.29	ND	0.08	ND	ND	ND	0.09	ND	ND	ND	ND	ND	0.05
Peyto 2 SPMD, triolein, June 1999	ng/g	ND	0.04	0.13	ND	ND	ND	ND	0.09	0.06	ND	ND	ND	0.05	0.06
Peyto 1 SPMD, triolein, July 1999	ng/g	ND	1.62	ND	0.15	0.17	ND	ND	1.17	0.20	ND	ND	0.55	0.55	0.14
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	0.25	0.17	0.04	0.06	ND	ND	0.24	0.12	ND	ND	0.10	ND	0.07

		PCBs														
Sample	Units	185	174	171	156	201/ 157	172/ 197	180	193	191	200	170	190	198	199	196/ 203
Bow PUF (18 Jun 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.4	ND	2.0	ND	ND
Bow PUF (08 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5	ND	ND	ND	ND
Bow PUF (29 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	6.9	ND	ND	ND	ND	ND	ND	ND
Bow PUF (17 Sep 1999)	pg/L	ND	6.1	ND	17.1	5.4	19.3	ND	ND	ND	ND	7.8	1.5	0.6	ND	ND
Peyto PUF (17 Jun 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2	ND	1.2	ND	ND
Peyto PUF (07 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	4.7	6.7	ND	ND	ND	ND	8.4	ND	ND
Peyto PUF (28 Jul 1999)	pg/L	ND	ND	ND	ND	ND	30.9	ND	ND	ND	ND	ND	ND	2.5	ND	ND
Peyto PUF (16 Sep 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.3	ND	ND
PUF blank, July 1999	pg/L	7.7	30.3	ND	88.9	28.7	5.0	51.1	ND	ND	6.0	27.7	5.3	3.3	ND	ND
PUF blank, September 1999	pg/L	ND	5.9	ND	11.3	0.9	ND	6.1	1.8	ND	ND	5.0	ND	1.9	ND	ND
Bow 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	0.08	0.03	ND	ND	0.02	ND	ND	ND	ND
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	0.01	0.02	ND	ND	ND	ND	ND	ND	ND
Bow 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	0.03	0.04	ND	ND	0.01	ND	ND	ND	ND
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	0.03	0.02	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	0.03	0.00	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	0.02	0.03	ND	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.02	ND	ND	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.04	ND	ND	ND	0.06	ND	ND	ND	ND
Bow 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.03	0.02	ND	ND	ND	ND	ND	ND	ND
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.01	0.04	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.05	0.05	ND	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, triolein, August 1999	ng/g	ND	0.13	ND	ND	ND	ND	0.15	ND	ND	ND	0.03	ND	ND	ND	ND
Bow 1 SPMD, almond oil, August 1999	ng/g	ND	0.12	ND	ND	ND	ND	0.13	0.01	ND	ND	0.06	ND	ND	0.03	ND
Bow 2 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	0.03	0.03	ND	ND	ND	ND	ND	ND	ND
Bow 2 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	0.04	0.01	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	0.02	0.01	ND	ND	ND	ND	ND	ND	ND
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	0.08	0.10	ND	ND	ND	ND	ND	ND	ND
Peyto 2 SPMD, triolein, June 1999	ng/g	ND	0.03	ND	ND	ND	ND	0.02	ND	ND	ND	ND	ND	ND	ND	ND
Peyto 1 SPMD, triolein, July 1999	ng/g	0.06	ND	ND	ND	ND	ND	0.40	0.13	ND	ND	ND	ND	ND	ND	ND
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.04	0.03	ND	ND	ND	ND	ND	ND	ND

		PCBs								DDT Isomers					
Sample	Units	189	208	195	207	194	205	206	209	o,p-DDE	p,p-DDE	o,p-DDD	p,p-DDD	o,p-DDT	p,p-DDT
Bow PUF (18 Jun 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	1.8	16.4	6.0	4.7	ND	3.7
Bow PUF (08 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	20.6	ND	6.6	4.4	7.4
Bow PUF (29 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	22.2	ND	ND
Bow PUF (17 Sep 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	0.5	9.6	ND	5.2	0.4	7.9
Peyto PUF (17 Jun 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	5.3	9.2	6.2	3.6	ND	2.0
Peyto PUF (07 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.3	ND	6.7	8.5	14.1
Peyto PUF (28 Jul 1999)	pg/L	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	18.8	6.2	ND	ND
Peyto PUF (16 Sep 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	2.0	ND	8.1	6.4	4.8	4.6
PUF blank, July 1999	pg/L	2.2	1.8	ND	ND	3.6	ND	ND	ND	15.7	122.6	ND	ND	51.5	72.2
PUF blank, September 1999	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	2.0	13.5	ND	1.4	8.5	10.0
Bow 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.20	0.54	0.40	1.54	0.65	1.14
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.19	0.11	0.33	1.19	0.49	0.58
Bow 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.26	0.48	0.33	1.43	0.67	0.78
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.08	0.20	0.37	1.42	0.57	0.69
Bow 3 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.22	1.40	0.48	1.75	0.57	0.91
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.22	0.09	0.43	1.45	0.62	0.69
Bow 1 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.30	0.45	0.37	1.44	0.78	0.75
Bow 1 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.22	0.49	0.39	1.42	0.77	0.87
Bow 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.21	0.39	0.28	1.62	0.69	0.82
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.22	0.33	0.40	1.48	0.72	0.81
Bow 3 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.31	0.58	0.41	1.60	0.76	0.79
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.24	0.91	0.43	1.58	0.66	0.78
Bow 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.43	0.79	1.01	2.98	1.43	2.08
Bow 1 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.42	0.68	0.85	3.19	1.52	2.16
Bow 2 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.43	1.22	0.87	2.84	1.28	1.74
Bow 2 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.37	0.51	0.54	2.20	1.02	1.21
Bow 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.55	0.93	1.00	3.29	1.49	1.97
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.43	0.70	0.85	2.91	1.29	1.66
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.20	0.29	0.50	1.66	0.81	1.02
Peyto 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.33	0.46	0.38	1.27	0.85	0.72
Peyto 1 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.28	7.47	0.38	1.43	0.84	1.08
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.23	0.23	0.38	1.18	0.65	0.68

Sample	Units	Chlorobenzenes				Hexachlorocyclohexanes				Cyclodienes				
		1245-TCBz	1234-TCBz	PCBz	HCBz	a-HCH	b-HCH	g-HCH	d-HCH	C	Heptachlor	U1	C1A	C1B/U6
Bow PUF (18 Jun 1999)	pg/L	ND	3.5	3.0	10.8	119.7	4.7	107.5	ND	ND	ND	ND	ND	ND
Bow PUF (08 Jul 1999)	pg/L	ND	5.8	1.4	8.5	105.6	4.6	85.9	ND	ND	ND	ND	1.8	0.3
Bow PUF (29 Jul 1999)	pg/L	ND	3.8	2.0	5.9	143.5	5.3	100.4	ND	ND	ND	ND	2.4	ND
Bow PUF (17 Sep 1999)	pg/L	ND	ND	ND	6.9	123.4	5.3	87.5	ND	ND	ND	ND	1.2	ND
Peyto PUF (17 Jun 1999)	pg/L	ND	5.1	3.3	11.4	174.3	6.2	125.7	ND	ND	ND	ND	ND	ND
Peyto PUF (07 Jul 1999)	pg/L	ND	5.3	1.9	5.4	147.9	6.1	102.8	ND	ND	ND	ND	1.9	0.5
Peyto PUF (28 Jul 1999)	pg/L	ND	4.3	4.4	4.1	155.6	6.3	128.7	ND	ND	ND	ND	1.6	0.0
Peyto PUF (16 Sep 1999)	pg/L	ND	ND	ND	4.6	153.1	3.1	91.2	ND	ND	0.9	ND	ND	ND
PUF blank, July 1999	pg/L	ND	ND	ND	3.2	1.1	ND	4.8	ND	0.7	ND	ND	ND	0.7
PUF blank, September 1999	pg/L	ND	ND	ND	0.7	0.6	1.9	1.7	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, triolein, June 1999	ng/g	ND	0.19	0.54	1.97	1.94	ND	1.18	ND	0.05	ND	0.04	ND	ND
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	0.24	0.69	2.64	1.96	ND	1.15	ND	0.02	0.12	0.03	ND	ND
Bow 2 SPMD, triolein, June 1999	ng/g	ND	0.48	0.81	2.28	1.57	ND	1.24	ND	0.09	ND	0.08	ND	ND
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	0.24	0.68	2.35	1.91	ND	1.15	ND	0.02	ND	0.04	ND	ND
Bow 3 SPMD, triolein, June 1999	ng/g	ND	0.28	0.65	2.50	1.86	ND	1.16	ND	0.04	ND	0.05	ND	ND
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	0.30	0.89	3.45	1.89	ND	1.13	ND	0.02	0.11	0.03	ND	ND
Bow 1 SPMD, triolein, July 1999	ng/g	ND	0.29	0.76	2.67	1.79	0.06	1.42	ND	0.11	ND	0.05	ND	ND
Bow 1 SPMD, almond oil, July 1999	ng/g	ND	0.37	0.93	2.73	1.69	0.06	1.27	ND	0.17	ND	0.03	ND	ND
Bow 2 SPMD, triolein, July 1999	ng/g	ND	0.12	0.50	2.36	2.11	ND	1.24	ND	ND	ND	ND	ND	ND
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	0.28	0.93	2.46	1.64	0.07	1.26	ND	0.02	ND	0.04	ND	ND
Bow 3 SPMD, triolein, July 1999	ng/g	ND	0.41	1.03	3.00	1.67	0.06	1.33	ND	0.07	ND	0.09	ND	ND
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	0.09	0.69	2.74	2.12	ND	1.27	ND	0.02	ND	0.03	ND	ND
Bow 1 SPMD, triolein, August 1999	ng/g	ND	0.16	0.48	3.96	2.75	ND	1.69	ND	0.06	ND	0.08	ND	ND
Bow 1 SPMD, almond oil, August 1999	ng/g	ND	0.06	0.52	4.11	2.53	ND	1.52	ND	0.04	ND	0.07	ND	ND
Bow 2 SPMD, triolein, August 1999	ng/g	ND	0.11	0.66	4.22	2.85	0.11	1.70	ND	0.05	ND	0.06	ND	ND
Bow 2 SPMD, almond oil, August 1999	ng/g	ND	0.08	0.80	4.95	3.13	ND	1.77	ND	0.02	0.13	0.03	ND	ND
Bow 3 SPMD, triolein, August 1999	ng/g	ND	0.15	0.70	5.32	2.88	ND	1.73	ND	0.07	ND	0.05	ND	ND
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	0.15	0.88	5.91	3.01	ND	1.64	ND	0.05	0.09	0.04	ND	ND
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	0.22	0.65	2.43	2.49	ND	1.35	ND	0.08	ND	0.09	ND	ND
Peyto 2 SPMD, triolein, June 1999	ng/g	ND	0.40	0.93	2.39	2.05	ND	1.40	ND	0.09	ND	0.11	ND	ND
Peyto 1 SPMD, triolein, July 1999	ng/g	ND	0.12	0.54	2.06	2.06	ND	1.28	ND	0.10	ND	0.08	ND	0.06
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	0.15	0.48	1.83	1.97	ND	1.23	ND	0.05	ND	0.08	ND	ND

Sample	Units	Cyclodienes									
		OCS	Heptachlor epoxide	Oxy-chlordane	C3	C2/ U5	t-chlordane	C5	U3	c-chlordane	t-nonachlor
Bow PUF (18 Jun 1999)	pg/L	ND	16.5	0.3	ND	ND	0.4	ND	ND	2.2	3.8
Bow PUF (08 Jul 1999)	pg/L	ND	16.7	ND	2.5	ND	ND	4.7	ND	1.6	1.9
Bow PUF (29 Jul 1999)	pg/L	ND	17.9	0.4	ND	2.0	ND	ND	ND	ND	0.0
Bow PUF (17 Sep 1999)	pg/L	ND	16.1	ND	1.9	1.0	1.4	ND	ND	2.0	2.0
Peyto PUF (17 Jun 1999)	pg/L	ND	18.0	0.3	2.9	ND	1.1	6.7	ND	2.6	4.8
Peyto PUF (07 Jul 1999)	pg/L	ND	19.8	0.3	2.6	1.0	2.1	ND	ND	3.1	3.4
Peyto PUF (28 Jul 1999)	pg/L	ND	17.5	0.1	ND	ND	ND	6.0	ND	ND	2.1
Peyto PUF (16 Sep 1999)	pg/L	ND	19.3	1.7	2.6	1.0	2.2	4.1	ND	4.7	4.6
PUF blank, July 1999	pg/L	0.4	2.2	0.9	3.2	ND	9.2	ND	ND	10.4	7.4
PUF blank, September 1999	pg/L	ND	ND	0.9	ND	ND	4.0	ND	ND	4.4	3.0
Bow 1 SPMD, triolein, June 1999	ng/g	ND	ND	0.14	0.14	0.06	0.27	0.29	0.07	0.64	0.65
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	ND	0.15	0.13	0.05	0.26	0.25	0.05	0.58	0.56
Bow 2 SPMD, triolein, June 1999	ng/g	ND	ND	0.15	0.12	ND	0.32	0.31	0.08	0.66	0.80
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	ND	0.15	0.05	ND	0.28	0.26	0.09	0.66	0.60
Bow 3 SPMD, triolein, June 1999	ng/g	ND	ND	0.18	0.15	0.05	0.30	0.30	0.12	0.73	0.74
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	ND	0.18	0.11	0.04	0.32	0.29	0.09	0.72	0.67
Bow 1 SPMD, triolein, July 1999	ng/g	0.01	ND	0.14	0.18	0.07	0.28	0.30	ND	0.72	0.84
Bow 1 SPMD, almond oil, July 1999	ng/g	0.02	1.42	0.15	0.13	0.04	0.33	0.32	ND	0.74	0.79
Bow 2 SPMD, triolein, July 1999	ng/g	ND	ND	0.16	ND	ND	0.27	ND	ND	0.71	0.73
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	1.30	0.16	0.08	ND	0.31	0.29	ND	0.74	0.74
Bow 3 SPMD, triolein, July 1999	ng/g	ND	ND	0.17	0.18	ND	0.36	0.40	0.10	0.74	0.90
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	ND	0.22	0.20	0.08	0.38	0.35	0.10	0.78	0.73
Bow 1 SPMD, triolein, August 1999	ng/g	ND	2.35	0.33	0.33	0.08	0.59	0.60	0.19	1.39	1.41
Bow 1 SPMD, almond oil, August 1999	ng/g	ND	2.18	0.30	0.35	0.10	0.61	0.62	ND	1.43	1.40
Bow 2 SPMD, triolein, August 1999	ng/g	ND	ND	0.35	0.39	0.13	0.57	0.63	0.16	1.41	1.35
Bow 2 SPMD, almond oil, August 1999	ng/g	0.14	ND	0.31	0.24	0.11	0.56	0.55	0.12	1.28	1.19
Bow 3 SPMD, triolein, August 1999	ng/g	ND	ND	0.46	0.45	0.11	0.75	0.70	0.19	1.65	1.60
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	ND	0.43	0.36	0.12	0.68	0.63	0.14	1.58	1.49
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	ND	0.23	0.21	0.06	0.51	0.41	0.13	1.02	1.17
Peyto 2 SPMD, triolein, June 1999	ng/g	ND	ND	0.18	0.06	ND	0.49	0.37	0.11	0.92	1.17
Peyto 1 SPMD, triolein, July 1999	ng/g	0.04	ND	0.27	0.22	0.08	0.54	0.45	0.13	1.04	1.33
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	ND	0.24	0.21	0.09	0.50	0.35	ND	1.02	1.06

		Cyclodienes					Toxaphene							
Sample	Units	c-nonachlor	Endo-sulfan	Dieldrin	Endrin	Endrin Aldehyde	Tsed.	T1	T2/ P26	T3	T4	P32	T5	T6
Bow PUF (18 Jun 1999)	pg/L	0.6	37.5	19.1	8.1	ND	7.1	2.0	3.0	3.8	ND	ND	ND	ND
Bow PUF (08 Jul 1999)	pg/L	1.9	17.5	18.7	6.5	ND	3.6	ND	13.5	1.3	ND	ND	1.5	ND
Bow PUF (29 Jul 1999)	pg/L	1.8	22.8	24.5	10.9	ND	9.2	ND	12.9	ND	ND	ND	ND	ND
Bow PUF (17 Sep 1999)	pg/L	1.4	16.6	19.5	8.3	ND	5.4	1.5	9.0	2.5	9.3	ND	ND	ND
Peyto PUF (17 Jun 1999)	pg/L	0.4	27.1	18.3	9.3	ND	5.6	3.2	4.3	4.1	ND	ND	ND	ND
Peyto PUF (07 Jul 1999)	pg/L	1.2	23.1	20.9	10.0	ND	4.9	ND	14.6	2.1	ND	ND	ND	ND
Peyto PUF (28 Jul 1999)	pg/L	0.7	43.7	19.3	9.2	ND	9.1	ND	11.5	4.4	ND	ND	ND	ND
Peyto PUF (16 Sep 1999)	pg/L	2.1	24.0	24.9	10.1	ND	5.7	ND	10.0	3.8	ND	ND	4.5	ND
PUF blank, July 1999	pg/L	ND	7.8	5.7	ND	ND	ND	13.8	ND	ND	ND	ND	ND	2.9
PUF blank, September 1999	pg/L	0.5	5.8	5.1	ND	ND	ND	1.5	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, triolein, June 1999	ng/g	0.36	ND	ND	ND	ND	0.76	0.37	1.39	0.46	0.61	ND	0.49	ND
Bow 1 SPMD, almond oil, June 1999	ng/g	0.25	ND	ND	ND	ND	0.63	0.23	1.11	0.34	0.51	ND	0.38	ND
Bow 2 SPMD, triolein, June 1999	ng/g	0.26	ND	0.32	ND	ND	0.96	0.38	1.52	0.44	0.56	ND	0.29	ND
Bow 2 SPMD, almond oil, June 1999	ng/g	0.33	ND	ND	ND	ND	0.72	0.29	1.16	0.39	0.54	ND	0.19	ND
Bow 3 SPMD, triolein, June 1999	ng/g	0.33	ND	ND	ND	ND	0.80	0.34	1.57	0.47	0.64	ND	0.50	ND
Bow 3 SPMD, almond oil, June 1999	ng/g	0.30	ND	ND	ND	ND	0.76	0.30	1.26	0.38	0.61	ND	0.36	ND
Bow 1 SPMD, triolein, July 1999	ng/g	0.31	ND	ND	ND	ND	0.95	0.35	1.69	0.33	0.60	ND	0.67	0.32
Bow 1 SPMD, almond oil, July 1999	ng/g	0.27	3.33	2.48	0.87	ND	1.03	0.43	1.75	0.48	0.65	ND	0.54	ND
Bow 2 SPMD, triolein, July 1999	ng/g	0.36	ND	ND	ND	ND	0.83	0.34	1.51	0.51	0.62	ND	0.57	ND
Bow 2 SPMD, almond oil, July 1999	ng/g	0.28	3.39	2.40	0.86	ND	0.98	0.43	1.57	0.51	0.66	ND	0.47	ND
Bow 3 SPMD, triolein, July 1999	ng/g	0.34	ND	0.16	0.17	ND	1.01	0.39	1.82	0.50	0.62	ND	0.56	ND
Bow 3 SPMD, almond oil, July 1999	ng/g	0.38	ND	ND	ND	ND	0.78	0.33	1.39	0.46	0.63	ND	0.56	ND
Bow 1 SPMD, triolein, August 1999	ng/g	0.82	5.02	4.12	1.88	ND	1.70	0.71	3.41	1.03	1.45	ND	1.31	ND
Bow 1 SPMD, almond oil, August 1999	ng/g	0.83	5.62	5.31	1.48	0.09	1.74	0.74	2.88	1.10	1.55	ND	1.33	ND
Bow 2 SPMD, triolein, August 1999	ng/g	0.76	ND	ND	ND	ND	1.58	0.65	3.11	0.93	1.26	ND	1.13	ND
Bow 2 SPMD, almond oil, August 1999	ng/g	0.60	ND	ND	ND	ND	1.39	0.53	1.08	0.69	ND	ND	ND	ND
Bow 3 SPMD, triolein, August 1999	ng/g	0.86	ND	ND	ND	ND	1.83	0.78	3.57	1.08	ND	ND	1.30	ND
Bow 3 SPMD, almond oil, August 1999	ng/g	0.74	ND	ND	ND	ND	1.58	0.67	2.89	0.86	1.33	ND	1.06	ND
Peyto 1 SPMD, triolein, June 1999	ng/g	0.45	ND	ND	ND	ND	0.94	0.35	1.83	0.55	0.66	ND	0.65	0.28
Peyto 2 SPMD, triolein, June 1999	ng/g	0.36	ND	0.24	0.04	ND	1.07	0.47	1.89	0.30	0.58	ND	ND	ND
Peyto 1 SPMD, triolein, July 1999	ng/g	0.50	ND	ND	ND	ND	0.96	0.33	1.98	0.57	0.65	ND	0.62	0.26
Peyto 2 SPMD, triolein, July 1999	ng/g	0.42	ND	ND	ND	ND	0.90	0.37	1.54	0.50	0.61	ND	0.52	ND

Sample	Units	Toxaphene CB3	T7	T8	T9	T10	T11	T12/ P50	T13	T14	CB5	T15	T16/ CB6	T17/ P62	CB8	T18
Bow PUF (18 Jun 1999)	pg/L	ND	ND	ND	9.5	8.8	2.9	39.4	6.0	ND	ND	1.0	ND	4.6	ND	ND
Bow PUF (08 Jul 1999)	pg/L	ND	1.9	ND	4.7	3.9	4.7	22.8	5.3	ND	ND	ND	ND	ND	ND	3.2
Bow PUF (29 Jul 1999)	pg/L	ND	ND	ND	5.9	2.4	1.7	11.8	4.2	ND	1.2	ND	ND	ND	ND	ND
Bow PUF (17 Sep 1999)	pg/L	ND	ND	ND	7.8	7.9	2.7	25.2	5.2	ND	ND	ND	1.5	1.4	ND	ND
Peyto PUF (17 Jun 1999)	pg/L	ND	7.6	ND	9.0	8.0	2.7	30.8	5.3	ND	ND	ND	ND	2.5	ND	ND
Peyto PUF (07 Jul 1999)	pg/L	ND	ND	ND	4.6	ND	5.1	20.1	2.4	ND	ND	ND	ND	ND	ND	ND
Peyto PUF (28 Jul 1999)	pg/L	ND	ND	ND	10.1	ND	ND	29.3	6.9	ND	ND	ND	ND	2.4	ND	ND
Peyto PUF (16 Sep 1999)	pg/L	ND	ND	ND	8.4	3.5	5.3	25.3	4.8	ND	ND	ND	1.7	1.7	ND	ND
PUF blank, July 1999	pg/L	ND	ND	ND	ND	ND	3.6	11.7	ND	ND	ND	1.6	ND	ND	ND	ND
PUF blank, September 1999	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	1.29	1.08	0.49	2.22	0.96	0.14	ND	ND	0.14	0.52	ND	ND
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	0.93	0.75	0.36	1.57	0.61	0.07	ND	ND	0.08	0.35	ND	ND
Bow 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	1.26	0.95	ND	2.17	0.88	0.12	ND	ND	0.10	0.40	ND	ND
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	1.11	0.89	0.43	1.81	0.72	ND	ND	ND	ND	0.37	ND	0.31
Bow 3 SPMD, triolein, June 1999	ng/g	ND	ND	ND	1.38	1.01	0.55	2.47	1.09	ND	ND	ND	0.14	0.57	ND	0.15
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	1.09	1.06	0.43	1.98	0.81	0.09	ND	ND	0.12	0.40	ND	ND
Bow 1 SPMD, triolein, July 1999	ng/g	0.16	0.14	ND	1.47	1.19	ND	2.39	1.00	ND	ND	ND	0.11	0.40	0.02	ND
Bow 1 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	1.37	1.06	0.51	2.44	0.96	0.16	ND	ND	0.09	0.48	ND	ND
Bow 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	1.40	1.10	0.56	2.68	1.12	ND	ND	0.04	0.16	0.66	ND	0.06
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	1.33	1.03	0.50	2.31	0.95	0.13	ND	ND	0.10	0.44	0.04	ND
Bow 3 SPMD, triolein, July 1999	ng/g	ND	ND	ND	1.41	1.10	0.56	2.48	0.99	ND	ND	ND	0.10	0.48	0.05	ND
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	1.32	1.07	0.53	2.29	0.96	0.09	ND	ND	0.13	0.50	ND	ND
Bow 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	3.00	2.65	1.48	5.45	2.45	0.42	ND	0.11	0.40	1.31	0.18	0.08
Bow 1 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	3.09	2.65	1.30	5.39	2.45	ND	ND	0.10	0.37	1.31	ND	ND
Bow 2 SPMD, triolein, August 1999	ng/g	ND	ND	ND	2.50	1.86	1.20	4.62	1.98	0.26	ND	ND	0.34	1.10	0.14	0.06
Bow 2 SPMD, almond oil, August 1999	ng/g	ND	0.24	ND	2.03	1.67	0.80	3.49	1.44	ND	ND	0.07	ND	1.04	ND	ND
Bow 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	3.01	2.60	1.29	5.46	2.37	0.35	ND	ND	0.36	1.33	0.15	ND
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	2.54	2.16	1.16	4.40	1.89	0.26	ND	0.06	0.27	1.00	0.09	ND
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	1.80	1.23	0.63	2.94	1.30	0.16	ND	ND	0.16	0.63	ND	ND
Peyto 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	1.44	0.95	ND	2.24	0.92	0.18	ND	ND	0.10	0.33	ND	ND
Peyto 1 SPMD, triolein, July 1999	ng/g	0.32	ND	ND	1.76	1.23	0.70	3.07	1.26	0.17	ND	0.14	0.14	0.66	ND	ND
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	1.41	0.96	0.45	2.12	0.92	0.06	ND	ND	0.11	0.37	ND	ND

		Toxaphene							Miscellaneous			
Sample	Units	CB9	T19	P69	CB11	Photo-mirex	Mirex	PCA	3Cl-Veratrol	4Cl-Veratrol	Dacthal	Methoxy-chlor
Bow PUF (18 Jun 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow PUF (08 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow PUF (29 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow PUF (17 Sep 1999)	pg/L	ND	ND	ND	ND	ND	5.1	ND	ND	ND	ND	12.6
Peyto PUF (17 Jun 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto PUF (07 Jul 1999)	pg/L	ND	ND	ND	ND	ND	1.6	ND	ND	ND	ND	ND
Peyto PUF (28 Jul 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto PUF (16 Sep 1999)	pg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PUF blank, July 1999	pg/L	ND	ND	ND	ND	ND	28.4	ND	ND	ND	ND	ND
PUF blank, September 1999	pg/L	ND	ND	ND	ND	ND	4.5	ND	ND	ND	ND	ND
Bow 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 2 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, almond oil, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 2 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.88
Bow 3 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, almond oil, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.02
Bow 1 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.15
Bow 2 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 2 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow 3 SPMD, almond oil, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto 1 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto 2 SPMD, triolein, June 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto 1 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto 2 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Sample	Units	Notes	% Recov. PCB 30	% Recov. OCN
Peyto 3 SPMD, triolein, July 1999	ng/g	Deployed 21 days	86.5	96.3
Peyto 1 SPMD, triolein, August 1999	ng/g	Deployed 50 days, F3 not run	88.0	93.8
Peyto 3 SPMD, triolein, August 1999	ng/g	Deployed 50 days, F3 not run	87.0	79.1
SPMD blank, triolein	ng/g	F3 not run	83.2	97.9
SPMD blank, triolein	ng/g	F3 not run	84.6	117.8
SPMD blank, almond oil	ng/g		91.6	72.5
SPMD blank, almond oil	ng/g	F3 not run	86.1	88.3
SPMD blank, almond oil	ng/g	F3 not run	85.3	76.7
Bow zooplankton (18 Jun 1999)	ng/g	4.3% lipid	76.4	88.6
Bow zooplankton (08 Jul 1999)	ng/g	6.9% lipid, F2 and F3 cloudy (lipid?)	72.8	101.1
Bow zooplankton (28 Jul 1999)	ng/g	11.6% lipid	95.7	69.6
Bow zooplankton (17 Sep 1999)	ng/g	10.9% lipid, F1 evaporated to dryness	84.8	87.6
Peyto zooplankton (17 Jun 1999)	ng/g	28.5% lipid	100.5	111.5
Peyto zooplankton (07 Jul 1999)	ng/g	32.0% lipid	91.0	99.5
Peyto zooplankton (27 Jul 1999)	ng/g	32.2% lipid	81.3	109.1
Peyto zooplankton (16 Sep 1999)	ng/g	22.3% lipid	87.9	132.2
Snowflake Lake, surface sediments	ng/g	11.3% organic carbon	79.0	60.2
Snowflake Lake, surface sediments	ng/g	9.9% organic carbon	98.4	62.8
Bow Lake sediments, 0-1 cm	ng/g	1.3% organic carbon, white crud in extract	94.3	129.7
Bow Lake sediments, 2-3 cm	ng/g	1.2% organic carbon	101.2	89.1
Bow Lake sediments, 4-5 cm	ng/g	1.0% organic carbon	88.1	95.8
Bow Lake sediments, 6-7 cm	ng/g	1.0% organic carbon	87.6	118.6
Bow Lake sediments, 10-11 cm	ng/g	0.3% organic carbon	91.9	83.3
Bow Lake sediments, 30-31 cm	ng/g	0.6% organic carbon	92.4	91.4
Bow Lake sediments, 40-41 cm	ng/g	0.6% organic carbon	98.2	105.9
Bow Lake sediments, 70-71 cm	ng/g	0.4% organic carbon	87.6	118.4
Bow Lake sediments, 140-141 cm	ng/g	used to blank correct other sediment slices	97.7	78.4
ASE Na2SO4 blank	ng/g		72.0	122.9
Freeze-drier Na2SO4 blank	ng/g		75.1	93.6
Ball mill Na2SO4 blank	ng/g	Evaporated F1 to dryness	102.8	127.4
Ball mill Na2SO4 blank	ng/g		91.6	145.9

		PCBs												
Sample	Units	7	6	8/5	19	18	27/ 24	16/ 32	26	25	31	28	33	22
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	0.06	ND	ND	ND	0.10	ND	ND	ND
Peyto 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.11	ND	ND	ND	ND
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.04	ND	ND	ND	ND
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	0.13	0.27	ND	0.10	0.39	0.67	0.60	ND
SPMD blank, triolein	ng/g	ND	ND	0.81	ND	ND	0.26	0.29	ND	0.24	0.20	0.76	0.55	ND
SPMD blank, almond oil	ng/g	ND	ND	0.43	ND	ND	0.18	0.14	0.14	0.15	0.30	0.35	0.19	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	0.29	ND	ND	0.11	0.27	0.37	0.30	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.29	ND	0.42	0.14	ND
Bow zooplankton (18 Jun 1999)	ng/g	ND	0.31	ND	ND	ND	ND	ND	ND	ND	ND	0.20	ND	ND
Bow zooplankton (08 Jul 1999)	ng/g	ND	ND	ND	ND	ND	0.04	ND	ND	ND	ND	0.15	ND	ND
Bow zooplankton (28 Jul 1999)	ng/g	ND	0.48	0.50	ND	1.00	0.24	0.21	ND	0.05	0.41	0.60	0.56	ND
Bow zooplankton (17 Sep 1999)	ng/g	ND	ND	ND	ND	0.30	0.11	0.12	ND	ND	0.05	0.29	0.28	ND
Peyto zooplankton (17 Jun 1999)	ng/g	ND	ND	0.12	ND	ND	0.13	0.22	ND	ND	0.03	0.53	0.15	ND
Peyto zooplankton (07 Jul 1999)	ng/g	ND	0.25	0.01	0.17	0.97	0.11	0.08	0.07	ND	ND	0.33	0.13	ND
Peyto zooplankton (27 Jul 1999)	ng/g	0.17	ND	0.49	ND	ND	0.11	0.21	ND	0.04	0.02	0.48	0.15	ND
Peyto zooplankton (16 Sep 1999)	ng/g	ND	0.38	0.33	ND	0.94	0.26	0.26	ND	0.07	0.49	0.63	0.42	ND
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	ND	0.224	ND	0.106	0.041	0.029	0.199	0.247	0.195	0.087
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	0.028	0.215	ND	0.102	0.042	0.024	0.210	0.363	0.204	0.057
Bow Lake sediments, 0-1 cm	ng/g	ND	ND	0.042	0.028	0.123	ND	ND	0.023	0.020	0.145	0.131	0.019	ND
Bow Lake sediments, 2-3 cm	ng/g	ND	0.073	0.029	0.007	0.121	ND	ND	0.027	0.091	0.192	0.197	0.013	ND
Bow Lake sediments, 4-5 cm	ng/g	0.043	0.105	0.104	0.055	0.211	ND	0.053	0.061	0.032	0.348	0.338	0.121	ND
Bow Lake sediments, 6-7 cm	ng/g	ND	ND	ND	0.005	0.077	ND	ND	ND	0.005	0.099	0.064	ND	ND
Bow Lake sediments, 10-11 cm	ng/g	ND	0.059	0.073	0.037	0.018	ND	0.026	0.018	0.051	0.129	0.173	0.078	0.033
Bow Lake sediments, 30-31 cm	ng/g	0.041	0.096	0.049	0.009	0.134	ND	ND	0.030	0.010	0.204	0.201	0.059	ND
Bow Lake sediments, 40-41 cm	ng/g	ND	ND	ND	0.027	0.051	ND	ND	0.018	ND	0.101	0.076	0.020	ND
Bow Lake sediments, 70-71 cm	ng/g	0.034	0.055	ND	0.008	ND	ND	ND	0.002	ND	0.038	ND	ND	ND
Bow Lake sediments, 140-141 cm	ng/g	ND	ND	0.231	0.068	0.200	0.109	0.090	0.046	0.048	0.284	0.335	0.238	0.105
ASE Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.029	0.024	ND	ND
Freeze-drier Na2SO4 blank	ng/g	ND	ND	0.035	0.064	ND	ND	ND	ND	0.017	0.018	0.023	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	ND	ND	0.165	ND	ND	ND	ND	0.050	ND	0.071	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	ND	0.322	ND	ND	ND	ND	ND	0.173	0.298	ND	ND	ND

		PCBs													
Sample	Units	45	46	52	49	47	48	44	42	64	40	74	70/ 76	66/ 95	60/ 56
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	0.17	ND	0.17	ND	ND	ND	0.00	ND	ND	0.01	0.01	0.05	0.12
Peyto 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.13	ND
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05	0.05	ND
SPMD blank, triolein	ng/g	ND	ND	0.59	ND	ND	ND	0.31	0.13	0.15	ND	0.10	0.22	0.19	ND
SPMD blank, triolein	ng/g	ND	ND	0.42	0.15	ND	ND	0.28	0.11	0.13	ND	0.11	0.24	0.29	ND
SPMD blank, almond oil	ng/g	ND	ND	0.15	ND	ND	ND	0.13	0.06	0.04	ND	0.08	0.26	0.10	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.08	0.14	0.17	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.14	0.09	0.17	ND
Bow zooplankton (18 Jun 1999)	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.04	ND	0.25	0.15	0.43	0.08
Bow zooplankton (08 Jul 1999)	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.05	ND	0.42	0.22	0.49	0.03
Bow zooplankton (28 Jul 1999)	ng/g	ND	ND	0.51	0.43	0.21	ND	0.20	0.17	0.08	ND	0.36	0.27	0.62	0.07
Bow zooplankton (17 Sep 1999)	ng/g	ND	ND	0.37	0.15	0.11	ND	0.14	ND	0.06	ND	0.56	0.25	0.21	ND
Peyto zooplankton (17 Jun 1999)	ng/g	ND	ND	0.58	1.29	0.49	0.20	0.21	0.18	0.12	ND	ND	0.34	1.62	0.15
Peyto zooplankton (07 Jul 1999)	ng/g	ND	ND	0.49	0.63	0.26	0.13	0.30	0.25	0.13	ND	0.22	0.41	1.50	0.14
Peyto zooplankton (27 Jul 1999)	ng/g	ND	ND	0.52	0.60	0.25	ND	0.29	0.16	0.15	ND	0.35	0.69	1.71	0.16
Peyto zooplankton (16 Sep 1999)	ng/g	ND	ND	0.92	0.53	0.26	ND	0.35	0.16	0.09	ND	0.38	0.35	0.49	ND
Snowflake Lake, surface sediments	ng/g	ND	ND	0.257	0.076	0.018	ND	0.152	ND	0.075	ND	0.118	0.210	0.331	ND
Snowflake Lake, surface sediments	ng/g	ND	ND	0.238	0.098	0.051	ND	0.151	ND	0.070	ND	0.136	0.228	0.343	ND
Bow Lake sediments, 0-1 cm	ng/g	ND	ND	0.142	0.099	0.034	0.016	0.028	0.034	ND	ND	0.012	0.033	0.161	ND
Bow Lake sediments, 2-3 cm	ng/g	ND	ND	0.084	0.045	0.010	0.057	ND	ND	ND	ND	0.066	0.095	0.213	ND
Bow Lake sediments, 4-5 cm	ng/g	ND	ND	0.406	0.262	0.106	0.074	0.104	0.075	0.025	ND	0.120	0.208	0.375	0.027
Bow Lake sediments, 6-7 cm	ng/g	ND	ND	0.066	0.065	0.028	0.009	ND	0.001	ND	ND	0.040	0.061	0.101	ND
Bow Lake sediments, 10-11 cm	ng/g	0.013	0.035	0.080	0.085	0.018	0.021	0.038	ND	0.022	ND	0.065	0.107	0.223	0.050
Bow Lake sediments, 30-31 cm	ng/g	ND	ND	0.173	0.117	0.054	0.029	0.054	0.049	ND	ND	0.053	0.107	0.207	ND
Bow Lake sediments, 40-41 cm	ng/g	ND	ND	0.078	0.061	0.032	0.011	0.032	0.029	ND	ND	0.015	0.034	0.055	ND
Bow Lake sediments, 70-71 cm	ng/g	ND	ND	0.041	0.035	0.014	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 140-141 cm	ng/g	0.028	0.026	0.198	0.128	0.059	0.076	0.138	0.080	0.088	ND	0.128	0.238	0.460	0.127
ASE Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Freeze-drier Na2SO4 blank	ng/g	0.098	ND	ND	0.026	ND	0.111	ND	ND	ND	ND	ND	ND	0.095	ND
Ball mill Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.062	ND
Ball mill Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	0.114	ND	ND	ND	ND	0.116	0.139	ND

		PCBs												
Sample	Units	84	101/89	99	97	87	136	110	82/151	135/144	149	118	134	114
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	0.26	0.18	0.45	0.33	0.16	0.17	0.14	ND	ND	1.92	ND	ND
Peyto 1 SPMD, triolein, August 1999	ng/g	0.20	0.34	ND	ND	0.12	ND	0.22	ND	ND	0.13	2.22	ND	ND
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	0.09	ND	0.16	ND	ND	0.14	1.69	ND	ND
SPMD blank, triolein	ng/g	ND	0.17	ND	ND	ND	ND	0.19	ND	ND	ND	0.24	ND	ND
SPMD blank, triolein	ng/g	ND	0.26	ND	ND	ND	ND	0.29	ND	ND	0.12	0.23	ND	ND
SPMD blank, almond oil	ng/g	ND	0.16	0.08	ND	0.06	ND	0.20	ND	ND	0.13	0.15	ND	ND
SPMD blank, almond oil	ng/g	ND	0.20	ND	ND	0.09	ND	0.19	ND	ND	ND	0.19	ND	ND
SPMD blank, almond oil	ng/g	ND	0.18	ND	ND	0.11	ND	0.34	ND	ND	0.22	0.29	ND	ND
Bow zooplankton (18 Jun 1999)	ng/g	ND	0.26	0.19	0.02	ND	ND	ND	0.26	ND	0.33	0.04	ND	ND
Bow zooplankton (08 Jul 1999)	ng/g	ND	0.09	0.10	0.01	ND	ND	ND	0.14	ND	ND	0.52	ND	ND
Bow zooplankton (28 Jul 1999)	ng/g	ND	0.50	0.18	0.12	0.12	ND	0.03	0.24	ND	0.62	0.47	ND	ND
Bow zooplankton (17 Sep 1999)	ng/g	ND	0.40	ND	0.13	0.11	ND	0.01	0.21	ND	0.73	1.04	ND	ND
Peyto zooplankton (17 Jun 1999)	ng/g	0.26	1.42	ND	0.55	0.46	0.44	1.03	0.53	ND	1.30	5.20	ND	ND
Peyto zooplankton (07 Jul 1999)	ng/g	0.22	0.85	ND	0.36	0.24	0.35	0.62	0.34	ND	0.75	3.88	0.04	ND
Peyto zooplankton (27 Jul 1999)	ng/g	0.32	1.26	ND	0.50	0.45	ND	1.06	0.55	ND	1.26	5.16	ND	ND
Peyto zooplankton (16 Sep 1999)	ng/g	ND	1.24	ND	0.53	0.45	ND	0.53	0.54	ND	4.56	2.95	ND	ND
Snowflake Lake, surface sediments	ng/g	ND	0.148	0.065	0.063	0.086	ND	0.205	0.126	0.040	0.151	ND	ND	0.033
Snowflake Lake, surface sediments	ng/g	ND	0.152	0.069	0.064	0.102	0.024	0.188	0.073	0.027	0.167	ND	ND	ND
Bow Lake sediments, 0-1 cm	ng/g	ND	0.048	0.076	0.006	0.019	0.104	ND	0.009	ND	0.051	0.108	ND	0.008
Bow Lake sediments, 2-3 cm	ng/g	ND	0.078	0.091	0.020	0.043	ND	0.031	0.003	ND	0.089	0.155	ND	ND
Bow Lake sediments, 4-5 cm	ng/g	ND	0.129	0.121	0.031	0.058	0.142	0.047	0.075	ND	0.141	0.135	ND	0.024
Bow Lake sediments, 6-7 cm	ng/g	ND	0.045	0.056	0.005	0.017	ND	ND	ND	ND	0.048	0.121	ND	0.018
Bow Lake sediments, 10-11 cm	ng/g	ND	0.082	ND	0.032	0.056	ND	0.109	0.205	0.060	0.142	ND	0.010	ND
Bow Lake sediments, 30-31 cm	ng/g	0.009	0.061	0.077	0.018	0.037	ND	0.013	0.015	0.017	0.062	0.124	ND	0.008
Bow Lake sediments, 40-41 cm	ng/g	ND	0.011	0.063	ND	0.000	ND	ND	ND	ND	ND	0.068	ND	ND
Bow Lake sediments, 70-71 cm	ng/g	ND	ND	0.046	ND	ND	0.084	ND	ND	ND	ND	0.072	ND	ND
Bow Lake sediments, 140-141 cm	ng/g	ND	0.134	ND	0.047	0.086	ND	0.156	0.086	0.037	0.155	ND	ND	ND
ASE Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	0.012	ND	ND	0.016	0.013	ND	ND
Freeze-drier Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	0.018	ND	0.028	ND	ND	0.020	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	0.086	0.040	ND	0.048	ND	0.131	ND	ND	0.132	0.156	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	0.324	ND	0.121	0.232	ND	0.524	ND	ND	0.514	0.533	ND	ND

		PCBs													
Sample	Units	131	153	132	105	141	137	130/ 176	138	158	129	178	187	183	128
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	0.24	0.20	ND	ND	ND	ND	0.03	ND	ND	0.13	0.16	0.18	ND
Peyto 1 SPMD, triolein, August 1999	ng/g	ND	0.37	ND	ND	0.04	ND	ND	0.15	0.08	ND	ND	0.13	ND	0.05
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	0.24	0.19	ND	ND	ND	ND	0.23	0.11	ND	ND	ND	ND	ND
SPMD blank, triolein	ng/g	ND	0.15	ND	0.08	ND	ND	ND	0.17	ND	ND	ND	ND	ND	ND
SPMD blank, triolein	ng/g	ND	0.34	ND	0.20	ND	ND	ND	0.28	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	0.17	0.07	0.06	ND	ND	ND	0.24	0.09	ND	ND	ND	ND	0.05
SPMD blank, almond oil	ng/g	ND	0.15	ND	0.14	ND	ND	ND	0.25	0.08	ND	ND	ND	ND	0.06
SPMD blank, almond oil	ng/g	ND	0.26	0.15	0.14	ND	ND	ND	0.44	0.12	ND	ND	ND	ND	ND
Bow zooplankton (18 Jun 1999)	ng/g	ND	0.71	0.07	ND	0.10	0.00	ND	0.14	ND	ND	0.08	0.56	0.34	ND
Bow zooplankton (08 Jul 1999)	ng/g	ND	0.10	0.01	ND	ND	ND	ND	ND	ND	ND	ND	0.37	0.17	ND
Bow zooplankton (28 Jul 1999)	ng/g	ND	0.11	ND	ND	0.07	ND	0.12	0.14	0.00	ND	ND	0.24	0.11	ND
Bow zooplankton (17 Sep 1999)	ng/g	ND	0.43	0.06	ND	0.09	0.01	ND	0.28	ND	ND	ND	0.35	0.23	ND
Peyto zooplankton (17 Jun 1999)	ng/g	ND	2.01	0.84	ND	0.29	0.08	ND	1.22	0.09	ND	0.34	1.50	0.72	0.13
Peyto zooplankton (07 Jul 1999)	ng/g	ND	0.92	0.60	ND	0.16	ND	ND	0.26	0.02	ND	0.29	1.13	0.63	ND
Peyto zooplankton (27 Jul 1999)	ng/g	ND	1.75	0.69	ND	0.27	ND	ND	1.01	0.08	ND	0.24	1.33	0.69	0.11
Peyto zooplankton (16 Sep 1999)	ng/g	ND	1.34	0.70	ND	0.30	0.04	ND	1.25	0.08	ND	0.25	0.85	0.72	ND
Snowflake Lake, surface sediments	ng/g	ND	0.147	ND	0.052	0.049	ND	ND	0.174	0.016	ND	0.032	0.088	0.040	ND
Snowflake Lake, surface sediments	ng/g	0.006	0.183	0.061	0.042	0.044	ND	0.060	0.190	0.018	ND	0.025	0.067	0.026	0.010
Bow Lake sediments, 0-1 cm	ng/g	ND	0.044	ND	ND	0.012	ND	ND	0.021	0.003	ND	ND	0.011	0.001	ND
Bow Lake sediments, 2-3 cm	ng/g	ND	0.110	0.006	0.004	0.023	ND	0.015	0.100	0.009	ND	0.009	0.030	0.008	0.003
Bow Lake sediments, 4-5 cm	ng/g	ND	0.088	ND	ND	0.031	ND	0.013	0.075	0.007	ND	0.004	0.031	0.013	ND
Bow Lake sediments, 6-7 cm	ng/g	ND	0.048	ND	ND	0.015	ND	ND	0.034	0.003	ND	0.001	0.017	0.004	ND
Bow Lake sediments, 10-11 cm	ng/g	ND	0.153	0.071	0.029	0.045	ND	0.018	0.152	0.014	ND	0.024	0.070	0.035	0.014
Bow Lake sediments, 30-31 cm	ng/g	ND	0.016	ND	ND	0.016	ND	0.000	0.008	0.000	ND	ND	0.002	ND	ND
Bow Lake sediments, 40-41 cm	ng/g	0.000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 70-71 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 140-141 cm	ng/g	0.013	0.142	0.092	0.034	0.039	ND	0.020	0.153	0.013	ND	0.021	0.065	0.026	0.008
ASE Na2SO4 blank	ng/g	ND	0.025	ND	ND	ND	0.105	ND	0.029	ND	ND	ND	ND	ND	ND
Freeze-drier Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	0.154	ND	ND	ND	ND	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	0.330	0.104	0.062	0.049	ND	ND	0.287	0.040	ND	ND	0.052	ND	0.041
Ball mill Na2SO4 blank	ng/g	ND	0.641	0.269	0.226	0.102	0.065	ND	0.922	0.132	ND	ND	ND	ND	0.161

Sample	Units	PCBs 185	174	171	156	201/157	172/197	180	193	191	200	170	190	198	199	196/203
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	0.06	0.06	ND	ND	0.02	ND	ND	ND	ND
Peyto 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	0.05	0.01	ND	ND	ND	ND	ND	ND	ND
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	0.05	0.07	ND	ND	0.04	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	0.05	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	0.07	0.09	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow zooplankton (18 Jun 1999)	ng/g	ND	ND	0.34	ND	0.09	0.04	0.42	1.14	ND	ND	0.19	0.06	ND	0.08	ND
Bow zooplankton (08 Jul 1999)	ng/g	ND	0.07	0.11	0.04	0.10	0.02	0.13	0.61	ND	ND	ND	ND	ND	0.09	ND
Bow zooplankton (28 Jul 1999)	ng/g	ND	0.08	ND	ND	ND	ND	0.12	ND	ND	ND	0.06	ND	ND	0.05	0.08
Bow zooplankton (17 Sep 1999)	ng/g	ND	ND	ND	ND	0.11	0.03	0.26	0.07	ND	ND	0.16	0.03	ND	0.11	ND
Peyto zooplankton (17 Jun 1999)	ng/g	ND	0.29	0.99	ND	0.39	0.09	1.10	ND	ND	ND	0.43	0.09	ND	0.18	0.26
Peyto zooplankton (07 Jul 1999)	ng/g	ND	ND	ND	ND	0.32	0.05	0.53	ND	0.03	0.06	0.21	0.05	ND	0.09	0.16
Peyto zooplankton (27 Jul 1999)	ng/g	ND	0.28	0.86	ND	0.36	0.06	0.91	ND	ND	ND	0.38	0.10	ND	0.13	0.20
Peyto zooplankton (16 Sep 1999)	ng/g	ND	ND	0.21	ND	0.20	0.06	0.58	0.08	ND	ND	0.61	0.04	ND	0.21	ND
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	ND	ND	0.005	0.035	ND	ND	ND	0.014	ND	ND	0.006	ND
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	ND	ND	ND	0.049	ND	ND	ND	0.012	ND	ND	ND	ND
Bow Lake sediments, 0-1 cm	ng/g	ND	ND	ND	ND	ND	ND	0.017	ND	ND	ND	0.001	0.002	ND	0.004	ND
Bow Lake sediments, 2-3 cm	ng/g	0.019	ND	ND	ND	ND	ND	0.035	ND	ND	ND	0.015	0.005	ND	0.013	ND
Bow Lake sediments, 4-5 cm	ng/g	ND	ND	ND	ND	ND	ND	0.021	ND	ND	ND	0.005	ND	ND	0.006	ND
Bow Lake sediments, 6-7 cm	ng/g	0.013	ND	ND	ND	ND	0.005	0.014	ND	ND	ND	0.005	ND	ND	0.007	ND
Bow Lake sediments, 10-11 cm	ng/g	ND	ND	ND	ND	ND	0.005	0.037	ND	ND	ND	0.014	0.003	ND	0.007	ND
Bow Lake sediments, 30-31 cm	ng/g	ND	ND	ND	ND	ND	ND	0.004	ND	ND	ND	ND	0.001	ND	0.000	ND
Bow Lake sediments, 40-41 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 70-71 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.000	ND
Bow Lake sediments, 140-141 cm	ng/g	ND	ND	ND	ND	ND	ND	0.028	ND	ND	ND	0.010	0.004	ND	0.004	ND
ASE Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Freeze-drier Na2SO4 blank	ng/g	ND	ND	0.013	ND	ND	ND	ND	0.218	ND	0.013	ND	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	0.031	ND	ND	ND	ND	0.129	0.082	ND	ND	0.038	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	0.161	0.177	ND	ND	0.115	ND	ND	ND	ND

		PCBs								DDT Isomers					
Sample	Units	189	208	195	207	194	205	206	209	o,p-DDE	p,p-DDE	o,p-DDD	p,p-DDD	o,p-DDT	p,p-DDT
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	0.04	ND	ND	ND	ND	ND	ND	0.44	0.52	0.49	1.81	1.28	1.14
Peyto 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.68	0.62	1.01	2.70	1.83	2.70
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.55	0.51	0.64	2.05	1.39	2.04
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.29	ND	ND	ND	0.12
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.12	ND	ND	0.05	0.17
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.87	ND	0.12	0.04	0.13
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.09	ND	0.10	ND	0.05
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.12	ND	0.10	ND	0.10
Bow zooplankton (18 Jun 1999)	ng/g	ND	ND	ND	ND	0.04	ND	0.04	ND	0.44	7.05	0.64	2.87	2.00	6.41
Bow zooplankton (08 Jul 1999)	ng/g	ND	0.06	ND	ND	0.06	ND	ND	ND	0.36	3.83	0.72	3.41	1.66	4.87
Bow zooplankton (28 Jul 1999)	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.55	4.96	1.06	3.52	1.75	4.20
Bow zooplankton (17 Sep 1999)	ng/g	ND	ND	ND	ND	0.08	ND	0.06	ND	0.55	6.47	1.31	5.13	2.68	7.42
Peyto zooplankton (17 Jun 1999)	ng/g	0.05	ND	ND	ND	ND	ND	0.10	ND	2.19	13.20	3.30	13.93	8.80	22.23
Peyto zooplankton (07 Jul 1999)	ng/g	0.04	ND	ND	ND	0.08	ND	0.04	ND	1.93	8.06	2.70	11.83	6.98	17.51
Peyto zooplankton (27 Jul 1999)	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	1.41	10.33	3.53	12.72	8.66	19.90
Peyto zooplankton (16 Sep 1999)	ng/g	ND	ND	ND	ND	0.12	ND	0.08	ND	1.62	9.23	2.57	9.18	7.97	23.14
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.055	0.567	0.223	1.489	0.081	0.431
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.057	0.761	0.024	2.534	0.091	0.449
Bow Lake sediments, 0-1 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.020	0.268	ND	0.062	0.028	0.175
Bow Lake sediments, 2-3 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.272	ND	0.168	0.143	0.773
Bow Lake sediments, 4-5 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.169	1.975	ND	0.487	0.189	2.023
Bow Lake sediments, 6-7 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.120	1.364	ND	0.757	0.091	1.514
Bow Lake sediments, 10-11 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.138	ND	0.030	0.040	0.053
Bow Lake sediments, 30-31 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.056	ND	0.032	0.011	0.020
Bow Lake sediments, 40-41 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.004	ND	ND
Bow Lake sediments, 70-71 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.002	ND	ND
Bow Lake sediments, 140-141 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.107	ND	0.016	0.053	0.054
ASE Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.022	ND	ND	ND	ND
Freeze-drier Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.012	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.606	0.047	0.099	0.072	0.094
Ball mill Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.794	ND	0.224	0.195	0.237

		Chlorobenzenes				Hexachlorocyclohexanes				Cyclodienes				
Sample	Units	1245-TCBz	1234-TCBz	PCBz	HCBz	a-HCH	b-HCH	g-HCH	d-HCH	C	Hepta chlor	U1	C1A	C1B/U6
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	0.26	0.70	2.80	1.59	ND	1.21	ND	0.20	ND	0.07	ND	ND
Peyto 1 SPMD, triolein, August 1999	ng/g	ND	0.02	0.40	2.86	1.98	0.07	1.15	ND	0.06	0.06	0.03	ND	ND
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	0.03	0.40	2.89	1.77	0.10	1.01	ND	0.07	0.09	0.06	ND	ND
SPMD blank, triolein	ng/g	ND	0.08	0.12	0.07	0.06	ND	0.05	ND	ND	ND	ND	ND	ND
SPMD blank, triolein	ng/g	ND	0.12	0.21	0.08	0.06	ND	0.08	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	0.23	0.20	0.08	0.09	0.13	0.08	ND	0,03	0.05	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	0.13	0.12	0.05	ND	ND	0.06	ND	0.02	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	0.12	0.07	0.09	ND	ND	0.07	ND	ND	ND	ND	ND	ND
Bow zooplankton (18 Jun 1999)	ng/g	ND	0.24	0.23	0.74	0.10	ND	0.14	ND	ND	ND	ND	ND	ND
Bow zooplankton (08 Jul 1999)	ng/g	ND	0.27	0.18	0.89	0.21	ND	0.29	ND	0.12	ND	ND	ND	0.02
Bow zooplankton (28 Jul 1999)	ng/g	ND	0.34	0.43	2.20	0.92	ND	0.84	ND	1.37	0.28	ND	ND	0.04
Bow zooplankton (17 Sep 1999)	ng/g	ND	0.22	0.39	1.77	0.71	0.07	0.63	ND	0.48	0.08	0.09	ND	0.04
Peyto zooplankton (17 Jun 1999)	ng/g	ND	1.05	0.64	3.45	1.66	0.09	1.40	ND	0.25	ND	0.30	ND	ND
Peyto zooplankton (07 Jul 1999)	ng/g	ND	0.54	0.45	2.87	1.31	0.10	1.16	ND	0.30	ND	0.13	ND	0.07
Peyto zooplankton (27 Jul 1999)	ng/g	ND	0.41	0.39	2.16	1.37	0.12	1.39	ND	0.44	0.02	0.28	ND	0.21
Peyto zooplankton (16 Sep 1999)	ng/g	ND	0.24	0.44	1.41	1.41	0.02	1.08	ND	1.39	0.47	0.17	ND	0.19
Snowflake Lake, surface sediments	ng/g			0.489	0.422	2.741	ND	0.126	0.033	0.010	ND	ND	ND	ND
Snowflake Lake, surface sediments	ng/g			0.443	0.366	1.795	ND	0.094	0.052	0.010	ND	ND	ND	ND
Bow Lake sediments, 0-1 cm	ng/g			0.173	0.303	0.085	0.019	0.062	ND	0.006	ND	0.027	0.012	ND
Bow Lake sediments, 2-3 cm	ng/g			0.234	0.315	0.083	ND	0.039	ND	0.007	ND	ND	ND	ND
Bow Lake sediments, 4-5 cm	ng/g			0.170	0.250	0.066	ND	0.053	ND	0.009	ND	ND	ND	ND
Bow Lake sediments, 6-7 cm	ng/g			0.030	0.060	0.011	ND	0.003	ND	0.001	ND	ND	ND	ND
Bow Lake sediments, 10-11 cm	ng/g			0.050	0.038	0.005	ND	0.011	ND	0.004	ND	ND	ND	ND
Bow Lake sediments, 30-31 cm	ng/g			0.112	0.129	0.033	ND	0.050	ND	0.006	ND	ND	ND	ND
Bow Lake sediments, 40-41 cm	ng/g			0.003	0.075	0.017	ND	0.026	ND	0.004	ND	ND	ND	ND
Bow Lake sediments, 70-71 cm	ng/g			0.006	0.048	0.023	ND	0.023	ND	0.004	ND	ND	ND	ND
Bow Lake sediments, 140-141 cm	ng/g			0.207	0.119	0.026	ND	0.047	ND	0.005	ND	ND	ND	ND
ASE Na_2SO_4 blank	ng/g			ND	0.005	0.005	ND	0.003	ND	ND	ND	ND	ND	ND
Freeze-drier Na_2SO_4 blank	ng/g			ND	ND	0.006	ND	ND	ND	ND	ND	ND	ND	ND
Ball mill Na_2SO_4 blank	ng/g	ND	ND	ND	0.017	ND	ND	0.017	ND	ND	ND	ND	ND	ND
Ball mill Na_2SO_4 blank	ng/g	ND	ND	ND	0.029	0.043	0.083	0.042	ND	ND	0.137	ND	ND	ND

		Cyclodienes									
Sample	Units	OCS	Heptachlor epoxide	Oxy-chlordane	C3	C2/ U5	t-chlordane	C5	U3	c-chlordane	t-nonachlor
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	0.99	0.39	0.08	ND	0.76	0.52	0.16	1.29	1.65
Peyto 1 SPMD, triolein, August 1999	ng/g	ND	ND	0.73	0.23	0.06	1.59	0.82	0.22	2.60	3.12
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	ND	0.58	0.40	0.09	1.32	0.66	0.18	2.22	2.61
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	0.02	ND	ND	0.04	0.02
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	0.04	ND	ND	0.07	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.04
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	0.04	ND
SPMD blank, almond oil	ng/g	ND	ND	0.02	ND	ND	ND	ND	ND	0.08	ND
Bow zooplankton (18 Jun 1999)	ng/g	0.11	0.44	0.00	ND	ND	0.62	ND	ND	1.21	2.04
Bow zooplankton (06 Jul 1999)	ng/g	0.08	0.59	0.03	0.18	0.08	0.62	0.51	0.08	1.29	1.82
Bow zooplankton (28 Jul 1999)	ng/g	0.11	1.07	0.35	0.27	0.13	1.41	0.88	0.10	2.25	2.81
Bow zooplankton (17 Sep 1999)	ng/g	0.11	1.02	0.36	0.28	0.10	1.45	0.94	0.15	2.56	3.61
Peyto zooplankton (17 Jun 1999)	ng/g	0.13	3.00	0.74	1.04	0.39	4.56	2.81	0.59	7.41	12.90
Peyto zooplankton (07 Jul 1999)	ng/g	0.17	2.35	0.67	0.92	0.37	3.78	2.41	0.63	6.48	10.68
Peyto zooplankton (27 Jul 1999)	ng/g	0.27	2.88	0.96	1.10	0.43	4.80	2.96	0.57	8.06	14.02
Peyto zooplankton (16 Sep 1999)	ng/g	0.28	2.19	1.19	0.70	0.14	5.32	2.24	0.38	7.85	14.06
Snowflake Lake, surface sediments	ng/g	ND	0.270	ND	ND	0.011	0.041	ND	ND	0.027	0.024
Snowflake Lake, surface sediments	ng/g	0.081	ND	ND	0.005	0.020	ND	ND	ND	0.028	0.017
Bow Lake sediments, 0-1 cm	ng/g	ND	0.045	0.156	ND	ND	0.017	ND	ND	0.024	0.037
Bow Lake sediments, 2-3 cm	ng/g	ND	0.015	ND	ND	ND	ND	ND	ND	ND	0.033
Bow Lake sediments, 4-5 cm	ng/g	ND	0.042	ND	ND	ND	ND	ND	ND	0.024	0.019
Bow Lake sediments, 6-7 cm	ng/g	ND	0.041	ND	ND	ND	ND	ND	ND	0.002	ND
Bow Lake sediments, 10-11 cm	ng/g	ND	0.009	ND	ND	ND	0.007	0.002	ND	0.015	0.009
Bow Lake sediments, 30-31 cm	ng/g	ND	0.017	ND	ND	ND	ND	ND	ND	0.009	0.010
Bow Lake sediments, 40-41 cm	ng/g	ND	0.005	0.006	ND	ND	0.011	ND	ND	0.009	ND
Bow Lake sediments, 70-71 cm	ng/g	ND	0.000	ND	ND	ND	0.011	ND	ND	0.003	0.002
Bow Lake sediments, 140-141 cm	ng/g	ND	0.019	0.059	ND	ND	0.012	0.009	ND	0.009	0.016
ASE Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Freeze-drier Na2SO4 blank	ng/g	ND	0.007	ND	ND	ND	ND	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	0.030	0.037	ND	ND	ND	ND	ND	0.031	0.216
Ball mill Na2SO4 blank	ng/g	ND	0.085	0.142	ND	ND	ND	ND	ND	0.047	0.566

Sample	Units	Cyclodienes					Toxaphene							
		c-nonachlor	Endo-sulfan	Dieldrin	Endrin	Endrin Aldehyde	Tsed.	T1	T2/ P26	T3	T4	P32	T5	T6
Peyto 3 SPMD, triolein, July 1999	ng/g	0.50	0.42	0.06	ND	ND	1.32	0.60	2.60	0.72	0.91	ND	0.34	0.34
Peyto 1 SPMD, triolein, August 1999	ng/g	1.10	ND	ND	ND	ND	1.88	0.85	4.18	1.03	1.64	ND	0.66	ND
Peyto 3 SPMD, triolein, August 1999	ng/g	0.89	ND	ND	ND	ND	1.58	0.71	3.58	0.83	1.39	ND	1.00	ND
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	0.08	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow zooplankton (18 Jun 1999)	ng/g	1.09	0.68	1.05	0.41	ND	0.51	0.30	1.79	0.32	ND	ND	ND	ND
Bow zooplankton (08 Jul 1999)	ng/g	1.08	1.26	1.26	0.48	ND	0.66	0.36	1.78	0.50	ND	ND	ND	ND
Bow zooplankton (28 Jul 1999)	ng/g	1.58	1.25	2.32	0.61	ND	0.97	0.56	2.69	0.60	ND	ND	ND	ND
Bow zooplankton (17 Sep 1999)	ng/g	2.24	1.05	2.40	0.59	ND	1.00	0.68	3.25	0.73	ND	ND	0.88	ND
Peyto zooplankton (17 Jun 1999)	ng/g	4.76	3.48	7.25	3.38	ND	3.41	1.74	9.86	2.23	ND	ND	2.59	ND
Peyto zooplankton (07 Jul 1999)	ng/g	4.14	7.53	6.20	2.44	0.17	2.90	1.52	8.29	1.78	ND	ND	2.23	ND
Peyto zooplankton (27 Jul 1999)	ng/g	5.47	9.05	7.58	2.68	ND	3.71	1.91	10.62	2.34	ND	ND	2.65	ND
Peyto zooplankton (16 Sep 1999)	ng/g	6.62	4.20	6.04	2.02	ND	2.42	1.70	8.73	1.60	ND	ND	ND	ND
Snowflake Lake, surface sediments	ng/g	0.009	0.079	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Snowflake Lake, surface sediments	ng/g	ND	0.027	0.148	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 0-1 cm	ng/g	ND	0.039	ND	ND	ND	0.006	ND	0.012	ND	ND	ND	ND	ND
Bow Lake sediments, 2-3 cm	ng/g	ND	0.041	0.231	ND	ND	0.012	ND	0.011	ND	ND	ND	ND	ND
Bow Lake sediments, 4-5 cm	ng/g	ND	0.032	0.067	ND	ND	ND	ND	0.007	ND	ND	ND	ND	ND
Bow Lake sediments, 6-7 cm	ng/g	ND	0.006	0.021	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 10-11 cm	ng/g	ND	0.067	0.074	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 30-31 cm	ng/g	ND	0.018	0.048	ND	ND	ND	ND	0.004	ND	ND	ND	ND	ND
Bow Lake sediments, 40-41 cm	ng/g	ND	0.040	0.015	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 70-71 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 140-141 cm	ng/g	ND	0.062	0.054	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ASE Na2SO4 blank	ng/g	ND	0.017	0.008	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Freeze-drier Na2SO4 blank	ng/g	ND	0.023	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	0.029	0.120	0.164	ND	ND	ND	ND	0.124	ND	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	0.085	0.053	0.361	ND	ND	ND	ND	0.429	ND	ND	ND	ND	ND

		Toxaphene														
Sample	Units	CB3	T7	T8	T9	T10	T11	T12/ P50	T13	T14	CB5	T15	T16/ CB6	T17/ P62	CB8	T18
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	ND	ND	2.03	1.37	ND	3.43	1.35	0.16	ND	0.06	0.13	0.62	0.12	ND
Peyto 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	3.39	2.38	1.31	5.99	2.26	0.26	ND	0.09	0.40	1.27	0.14	ND
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	2.74	1.92	1.07	4.73	1.77	0.20	ND	0.18	0.31	0.98	0.11	0.04
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.03	ND	ND
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	0.05	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	0.15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow zooplankton (18 Jun 1999)	ng/g	ND	0.16	ND	2.04	1.07	ND	4.38	1.36	0.16	ND	0.66	0.43	1.69	0.31	0.07
Bow zooplankton (08 Jul 1999)	ng/g	ND	0.21	ND	2.21	1.30	0.76	4.38	1.65	ND	ND	0.77	0.43	1.64	0.23	0.08
Bow zooplankton (28 Jul 1999)	ng/g	ND	0.04	ND	2.62	1.64	0.98	4.62	1.85	ND	0.35	0.61	0.50	1.70	0.26	0.09
Bow zooplankton (17 Sep 1999)	ng/g	ND	0.14	ND	3.72	2.79	1.42	7.21	2.73	ND	ND	1.01	0.84	2.96	0.40	0.18
Peyto zooplankton (17 Jun 1999)	ng/g	ND	ND	ND	10.41	5.21	3.34	19.28	6.83	0.92	ND	2.55	1.75	6.00	1.25	0.33
Peyto zooplankton (07 Jul 1999)	ng/g	ND	ND	ND	9.21	4.42	2.77	17.25	5.55	0.69	ND	1.68	1.56	5.17	0.78	0.27
Peyto zooplankton (27 Jul 1999)	ng/g	ND	ND	ND	11.64	7.06	3.46	21.26	7.48	1.14	ND	3.86	1.98	6.38	1.14	0.33
Peyto zooplankton (16 Sep 1999)	ng/g	ND	0.62	ND	10.73	4.83	3.31	19.68	6.02	0.78	ND	2.68	2.43	6.94	1.02	0.46
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 0-1 cm	ng/g	ND	ND	ND	ND	ND	ND	0.008	0.005	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 2-3 cm	ng/g	ND	ND	ND	0.010	0.003	0.006	0.010	0.007	ND	ND	0.004	ND	ND	ND	ND
Bow Lake sediments, 4-5 cm	ng/g	ND	ND	ND	0.004	ND	ND	0.004	0.004	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 6-7 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 10-11 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 30-31 cm	ng/g	ND	ND	ND	0.002	0.002	ND	ND	ND	ND	ND	0.006	ND	ND	ND	ND
Bow Lake sediments, 40-41 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 70-71 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow Lake sediments, 140-141 cm	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ASE Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Freeze-drier Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	0.222	ND	ND	ND	ND	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	0.264	ND	ND	ND	ND	0.567	ND	ND	ND	ND	ND	ND	ND	ND

Sample	Units	Toxaphene				Photo-mirex	Mirex	PCA	Miscellaneous		Dacthal	Methoxy-chlor
		CB9	T19	P69	CB11				3Cl-Veratrol	4Cl-Veratrol		
Peyto 3 SPMD, triolein, July 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto 1 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Peyto 3 SPMD, triolein, August 1999	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, triolein	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SPMD blank, almond oil	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bow zooplankton (18 Jun 1999)	ng/g	ND	ND	ND	ND	ND	0.31	ND	ND	ND	ND	0.47
Bow zooplankton (08 Jul 1999)	ng/g	ND	ND	ND	ND	ND	0.70	ND	ND	ND	ND	0.41
Bow zooplankton (28 Jul 1999)	ng/g	ND	ND	ND	ND	ND	0.05	ND	ND	ND	ND	0.32
Bow zooplankton (17 Sep 1999)	ng/g	ND	ND	ND	ND	ND	0.13	ND	ND	ND	ND	0.57
Peyto zooplankton (17 Jun 1999)	ng/g	ND	ND	ND	ND	ND	0.60	ND	ND	ND	ND	0.99
Peyto zooplankton (07 Jul 1999)	ng/g	ND	ND	ND	ND	ND	0.33	ND	ND	ND	ND	1.14
Peyto zooplankton (27 Jul 1999)	ng/g	ND	ND	ND	ND	ND	0.54	ND	ND	ND	ND	2.10
Peyto zooplankton (16 Sep 1999)	ng/g	ND	ND	ND	ND	ND	0.46	ND	ND	ND	ND	0.81
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	ND	ND	ND	0.064	ND	ND	ND	ND
Snowflake Lake, surface sediments	ng/g	ND	ND	ND	ND	ND	ND	0.058	ND	ND	ND	ND
Bow Lake sediments, 0-1 cm	ng/g	ND	ND	ND	ND	ND	ND	0.095	ND	ND	ND	ND
Bow Lake sediments, 2-3 cm	ng/g	ND	ND	ND	ND	ND	ND	0.041	ND	ND	ND	ND
Bow Lake sediments, 4-5 cm	ng/g	ND	ND	ND	ND	ND	ND	0.060	0.223	ND	ND	ND
Bow Lake sediments, 6-7 cm	ng/g	ND	ND	ND	ND	ND	ND	0.001	ND	ND	ND	ND
Bow Lake sediments, 10-11 cm	ng/g	ND	ND	ND	ND	ND	ND	0.018	ND	ND	ND	ND
Bow Lake sediments, 30-31 cm	ng/g	ND	ND	ND	ND	ND	ND	0.036	ND	ND	ND	ND
Bow Lake sediments, 40-41 cm	ng/g	ND	ND	ND	ND	ND	ND	0.010	ND	ND	ND	ND
Bow Lake sediments, 70-71 cm	ng/g	ND	ND	ND	ND	ND	ND	0.010	ND	ND	ND	ND
Bow Lake sediments, 140-141 cm	ng/g	ND	ND	ND	ND	ND	ND	0.052	ND	ND	ND	ND
ASE Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	0.003	ND	ND	ND	ND
Freeze-drier Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	0.052	ND	ND	ND	ND	ND
Ball mill Na2SO4 blank	ng/g	ND	ND	ND	ND	ND	0.065	ND	ND	ND	ND	ND

Appendix 3: Sparging Experimental Data

Solids concentration (mg/L)	Expt. Date	Time (min.)	Gas flow		Chemical	
0	15-Nov-99	0.00	250	mL/min	0.341	ng/mL DDT in water
0	15-Nov-99	30.23	250	mL/min	0.293	ng/mL DDT in water
0	15-Nov-99	65.60	250	mL/min	0.291	ng/mL DDT in water
0	15-Nov-99	96.92	250	mL/min	0.298	ng/mL DDT in water
0	15-Nov-99	126.73	250	mL/min	0.309	ng/mL DDT in water
0	15-Nov-99	161.52	250	mL/min	0.279	ng/mL DDT in water
0	15-Nov-99	192.97	250	mL/min	0.282	ng/mL DDT in water
0	15-Nov-99	192.97	48242	mL	1.544	ng DDT on XAD
0	24-Nov-99	0.00	315	mL/min	0.414	ng/mL DDT in water
0	24-Nov-99	46.35	325	mL/min	0.324	ng/mL DDT in water
0	24-Nov-99	91.12	331	mL/min	0.315	ng/mL DDT in water
0	24-Nov-99	130.00	330	mL/min	0.322	ng/mL DDT in water
0	24-Nov-99	171.90	336	mL/min	0.322	ng/mL DDT in water
0	24-Nov-99	211.50	331	mL/min	0.309	ng/mL DDT in water
0	24-Nov-99	254.50	329	mL/min	0.312	ng/mL DDT in water
0	24-Nov-99	254.50	84046	mL	8.627	ng DDT on XAD
0	29-Nov-99	0.00			0.004	ng/mL DDT in water
0	29-Nov-99	30.35	402	mL/min	0.450	ng/mL DDT in water
0	29-Nov-99	59.95	406	mL/min	0.433	ng/mL DDT in water
0	29-Nov-99	89.68	411	mL/min	0.419	ng/mL DDT in water
0	29-Nov-99	119.68	407	mL/min	0.418	ng/mL DDT in water
0	29-Nov-99	149.95	392	mL/min	0.419	ng/mL DDT in water
0	29-Nov-99	184.62	404	mL/min	0.417	ng/mL DDT in water
0	29-Nov-99	184.62	74519	mL	11.893	ng DDT on XAD
0	15-Apr-00	0.00			0.443	ng/mL DDT in water
0	15-Apr-00	30.60	386	mL/min	0.417	ng/mL DDT in water
0	15-Apr-00	60.92	391	mL/min	0.402	ng/mL DDT in water
0	15-Apr-00	92.05	377	mL/min	0.396	ng/mL DDT in water
0	15-Apr-00	122.60	373	mL/min	0.381	ng/mL DDT in water
0	15-Apr-00	152.97	369	mL/min	0.389	ng/mL DDT in water
0	15-Apr-00	183.08	376	mL/min	0.383	ng/mL DDT in water
0	15-Apr-00	183.08	69327	mL	14.519	ng DDT on XAD
0	21-Apr-00	0.00			0.547	ng/mL DDT in water
0	21-Apr-00	30.27	409	mL/min	0.488	ng/mL DDT in water
0	21-Apr-00	60.97	410	mL/min	0.478	ng/mL DDT in water
0	21-Apr-00	91.88	400	mL/min	0.473	ng/mL DDT in water
0	21-Apr-00	122.43	397	mL/min	0.466	ng/mL DDT in water
0	21-Apr-00	152.53	388	mL/min	0.460	ng/mL DDT in water
0	21-Apr-00	182.55	386	mL/min	0.463	ng/mL DDT in water
0	21-Apr-00	182.55	72726	mL	18.741	ng DDT on XAD
126	16-Apr-00	0.00			0.457	ng/mL DDT in water
126	16-Apr-00	30.13	393	mL/min	0.371	ng/mL DDT in water
126	16-Apr-00	60.38	382	mL/min	0.380	ng/mL DDT in water
126	16-Apr-00	91.00	378	mL/min	0.371	ng/mL DDT in water
126	16-Apr-00	121.28	374	mL/min	0.383	ng/mL DDT in water
126	16-Apr-00	151.42	382	mL/min	0.360	ng/mL DDT in water

Solids concentration (mg/L)	Expt. Date	Time (min.)	Gas flow		Chemical	
126	16-Apr-00	181.68	381	mL/min	0.382	ng/mL DDT in water
126	16-Apr-00	181.68	69339	mL	14.448	ng DDT on XAD
126	24-Apr-00	0.00			0.555	ng/mL DDT in water
126	24-Apr-00	30.13	394	mL/min	0.519	ng/mL DDT in water
126	24-Apr-00	60.33	394	mL/min	0.502	ng/mL DDT in water
126	24-Apr-00	90.55	383	mL/min	0.490	ng/mL DDT in water
126	24-Apr-00	120.68	386	mL/min	0.495	ng/mL DDT in water
126	24-Apr-00	150.83	377	mL/min	0.466	ng/mL DDT in water
126	24-Apr-00	181.13	381	mL/min	0.455	ng/mL DDT in water
126	24-Apr-00	181.13	69887	mL	20.944	ng DDT on XAD
251	17-Apr-00	0.00			0.499	ng/mL DDT in water
251	17-Apr-00	30.22	401	mL/min	0.491	ng/mL DDT in water
251	17-Apr-00	60.42	406	mL/min	0.493	ng/mL DDT in water
251	17-Apr-00	90.68	402	mL/min	0.480	ng/mL DDT in water
251	17-Apr-00	120.97	401	mL/min	0.460	ng/mL DDT in water
251	17-Apr-00	151.73	411	mL/min	0.457	ng/mL DDT in water
251	17-Apr-00	182.13	399	mL/min	0.458	ng/mL DDT in water
251	17-Apr-00	182.13	73464	mL	16.887	ng DDT on XAD
251	25-Apr-00	0.00			0.558	ng/mL DDT in water
251	25-Apr-00	30.12	394	mL/min	0.519	ng/mL DDT in water
251	25-Apr-00	60.33	397	mL/min	0.484	ng/mL DDT in water
251	25-Apr-00	90.90	381	mL/min	0.486	ng/mL DDT in water
251	25-Apr-00	121.47	380	mL/min	0.480	ng/mL DDT in water
251	25-Apr-00	151.78	373	mL/min	0.483	ng/mL DDT in water
251	25-Apr-00	182.23	383	mL/min	0.482	ng/mL DDT in water
251	25-Apr-00	182.23	70094	mL	16.899	ng DDT on XAD
503	18-Apr-00	0.00			0.550	ng/mL DDT in water
503	18-Apr-00	30.10	405	mL/min	0.533	ng/mL DDT in water
503	18-Apr-00	61.90	400	mL/min	0.527	ng/mL DDT in water
503	18-Apr-00	93.48	386	mL/min	0.525	ng/mL DDT in water
503	18-Apr-00	123.75	373	mL/min	0.512	ng/mL DDT in water
503	18-Apr-00	154.17	376	mL/min	0.500	ng/mL DDT in water
503	18-Apr-00	184.53	390	mL/min	0.515	ng/mL DDT in water
503	18-Apr-00	184.53	71671	mL	15.151	ng DDT on XAD
503	26-Apr-00	0.00			0.616	ng/mL DDT in water
503	26-Apr-00	30.42	382	mL/min	0.607	ng/mL DDT in water
503	26-Apr-00	60.83	391	mL/min	0.591	ng/mL DDT in water
503	26-Apr-00	91.53	375	mL/min	0.588	ng/mL DDT in water
503	26-Apr-00	121.80	369	mL/min	0.582	ng/mL DDT in water
503	26-Apr-00	152.17	380	mL/min	0.562	ng/mL DDT in water
503	26-Apr-00	183.17	376	mL/min	0.576	ng/mL DDT in water
503	26-Apr-00	183.17	69388	mL	20.207	ng DDT on XAD
1131	27-Apr-00	0.00			0.601	ng/mL DDT in water
1131	27-Apr-00	31.43	401	mL/min	0.603	ng/mL DDT in water
1131	27-Apr-00	64.87	405	mL/min	0.610	ng/mL DDT in water
1131	27-Apr-00	96.02	399	mL/min	0.616	ng/mL DDT in water

Solids concentration (mg/L)	Expt. Date	Time (min.)	Gas flow		Chemical	
1131	27-Apr-00	126.60	389	mL/min	0.618	ng/mL DDT in water
1131	27-Apr-00	157.45	380	mL/min	0.600	ng/mL DDT in water
1131	27-Apr-00	187.70	373	mL/min	0.605	ng/mL DDT in water
1131	27-Apr-00	187.70	73477	mL	17.007	ng DDT on XAD
1131	19-Apr-00	0.00			0.586	ng/mL DDT in water
1131	19-Apr-00	30.57	405	mL/min	0.567	ng/mL DDT in water
1131	19-Apr-00	60.75	415	mL/min	0.557	ng/mL DDT in water
1131	19-Apr-00	91.62	407	mL/min	0.559	ng/mL DDT in water
1131	19-Apr-00	121.90	391	mL/min	0.574	ng/mL DDT in water
1131	19-Apr-00	152.10	388	mL/min	0.567	ng/mL DDT in water
1131	19-Apr-00	182.50	380	mL/min	0.566	ng/mL DDT in water
1131	19-Apr-00	182.50	72579	mL	15.190	ng DDT on XAD
0	12-Nov-99	0.00	250	mL/min	0.394	ng/mL HCBz in water
0	12-Nov-99	30.03	250	mL/min	0.365	ng/mL HCBz in water
0	12-Nov-99	61.07	250	mL/min	0.322	ng/mL HCBz in water
0	12-Nov-99	91.88	250	mL/min	0.296	ng/mL HCBz in water
0	12-Nov-99	122.62	250	mL/min	0.267	ng/mL HCBz in water
0	12-Nov-99	152.98	250	mL/min	0.239	ng/mL HCBz in water
0	12-Nov-99	183.33	250	mL/min	0.234	ng/mL HCBz in water
0	12-Nov-99	183.33	45833	mL	76.986	ng HCBz on XAD
0	25-Nov-99	0.00	284	mL/min	0.413	ng/mL HCBz in water
0	25-Nov-99	33.02	287	mL/min	0.365	ng/mL HCBz in water
0	25-Nov-99	68.57	288	mL/min	0.326	ng/mL HCBz in water
0	25-Nov-99	96.32	289	mL/min	0.297	ng/mL HCBz in water
0	25-Nov-99	124.15	288	mL/min	0.271	ng/mL HCBz in water
0	25-Nov-99	153.37	287	mL/min	0.243	ng/mL HCBz in water
0	25-Nov-99	189.75	275	mL/min	0.219	ng/mL HCBz in water
0	25-Nov-99	189.75	54141	mL	152.958	ng HCBz on XAD
0	30-Nov-99	0.00			0.403	ng/mL HCBz in water
0	30-Nov-99	29.47	306	mL/min	0.367	ng/mL HCBz in water
0	30-Nov-99	59.43	307	mL/min	0.323	ng/mL HCBz in water
0	30-Nov-99	91.33	304	mL/min	0.296	ng/mL HCBz in water
0	30-Nov-99	121.28	304	mL/min	0.270	ng/mL HCBz in water
0	30-Nov-99	153.05	301	mL/min	0.242	ng/mL HCBz in water
0	30-Nov-99	188.42	289	mL/min	0.216	ng/mL HCBz in water
0	30-Nov-99	188.42	56802	mL	144.320	ng HCBz on XAD
0	13-Apr-00	0.00			0.435	ng/mL HCBz in water
0	13-Apr-00	25.05	422	mL/min	0.369	ng/mL HCBz in water
0	13-Apr-00	50.15	415	mL/min	0.324	ng/mL HCBz in water
0	13-Apr-00	76.22	414	mL/min	0.285	ng/mL HCBz in water
0	13-Apr-00	101.78	397	mL/min	0.242	ng/mL HCBz in water
0	13-Apr-00	127.13	395	mL/min	0.213	ng/mL HCBz in water
0	13-Apr-00	152.77	395	mL/min	0.184	ng/mL HCBz in water
0	13-Apr-00	152.77	62068	mL	216.153	ng HCBz on XAD
0	14-Apr-00	0.00			0.415	ng/mL HCBz in water
0	14-Apr-00	30.33	420	mL/min	0.348	ng/mL HCBz in water

Solids concentration (mg/L)	Expt. Date	Time (min.)	Gas flow		Chemical	
0	14-Apr-00	60.62	439	mL/min	0.282	ng/mL HCBz in water
0	14-Apr-00	91.03	426	mL/min	0.232	ng/mL HCBz in water
0	14-Apr-00	121.57	416	mL/min	0.202	ng/mL HCBz in water
0	14-Apr-00	152.05	412	mL/min	0.170	ng/mL HCBz in water
0	14-Apr-00	182.92	418	mL/min	0.145	ng/mL HCBz in water
0	14-Apr-00	182.92	77155	mL	241.616	ng HCBz on XAD
126	06-Apr-00	0.00			0.412	ng/mL HCBz in water
126	06-Apr-00	30.43	421	mL/min	0.345	ng/mL HCBz in water
126	06-Apr-00	60.88	427	mL/min	0.294	ng/mL HCBz in water
126	06-Apr-00	92.50	427	mL/min	0.253	ng/mL HCBz in water
126	06-Apr-00	122.70	408	mL/min	0.221	ng/mL HCBz in water
126	06-Apr-00	153.00	411	mL/min	0.183	ng/mL HCBz in water
126	06-Apr-00	183.33	408	mL/min	0.161	ng/mL HCBz in water
126	06-Apr-00	183.33	76466	mL	240.563	ng HCBz on XAD
126	07-Apr-00	0.00			0.419	ng/mL HCBz in water
126	07-Apr-00	30.72	422	mL/min	0.346	ng/mL HCBz in water
126	07-Apr-00	61.17	431	mL/min	0.301	ng/mL HCBz in water
126	07-Apr-00	92.47	433	mL/min	0.254	ng/mL HCBz in water
126	07-Apr-00	122.72	432	mL/min	0.213	ng/mL HCBz in water
126	07-Apr-00	153.67	429	mL/min	0.183	ng/mL HCBz in water
126	07-Apr-00	183.75	436	mL/min	0.160	ng/mL HCBz in water
126	07-Apr-00	183.75	79101	mL	163.729	ng HCBz on XAD
251	05-Apr-00	0.00			0.411	ng/mL HCBz in water
251	05-Apr-00	31.33	427	mL/min	0.348	ng/mL HCBz in water
251	05-Apr-00	61.68	435	mL/min	0.296	ng/mL HCBz in water
251	05-Apr-00	92.17	435	mL/min	0.259	ng/mL HCBz in water
251	05-Apr-00	122.80	434	mL/min	0.221	ng/mL HCBz in water
251	05-Apr-00	153.20	432	mL/min	0.183	ng/mL HCBz in water
251	05-Apr-00	183.72	428	mL/min	0.164	ng/mL HCBz in water
251	05-Apr-00	183.72	79331	mL	190.066	ng HCBz on XAD
251	08-Apr-00	0.00			0.401	ng/mL HCBz in water
251	08-Apr-00	30.35	425	mL/min	0.345	ng/mL HCBz in water
251	08-Apr-00	60.65	433	mL/min	0.288	ng/mL HCBz in water
251	08-Apr-00	91.32	432	mL/min	0.254	ng/mL HCBz in water
251	08-Apr-00	121.53	425	mL/min	0.219	ng/mL HCBz in water
251	08-Apr-00	152.07	419	mL/min	0.190	ng/mL HCBz in water
251	08-Apr-00	181.30	419	mL/min	0.167	ng/mL HCBz in water
251	08-Apr-00	181.30	77151	mL	227.316	ng HCBz on XAD
503	04-Apr-00	0.00			0.404	ng/mL HCBz in water
503	04-Apr-00	30.35	395	mL/min	0.355	ng/mL HCBz in water
503	04-Apr-00	61.28	405	mL/min	0.310	ng/mL HCBz in water
503	04-Apr-00	92.30	399	mL/min	0.268	ng/mL HCBz in water
503	04-Apr-00	123.45	387	mL/min	0.237	ng/mL HCBz in water
503	04-Apr-00	155.10	386	mL/min	0.215	ng/mL HCBz in water
503	04-Apr-00	186.27	386	mL/min	0.190	ng/mL HCBz in water
503	04-Apr-00	186.27	73194	mL	182.074	ng HCBz on XAD

Solids concentration (mg/L)	Expt. Date	Time (min.)	Gas flow		Chemical	
503	09-Apr-00	0.00			0.376	ng/mL HCBz in water
503	09-Apr-00	30.12	428	mL/min	0.333	ng/mL HCBz in water
503	09-Apr-00	60.42	437	mL/min	0.288	ng/mL HCBz in water
503	09-Apr-00	90.90	438	mL/min	0.259	ng/mL HCBz in water
503	09-Apr-00	121.33	440	mL/min	0.228	ng/mL HCBz in water
503	09-Apr-00	151.90	432	mL/min	0.201	ng/mL HCBz in water
503	09-Apr-00	182.28	432	mL/min	0.177	ng/mL HCBz in water
503	09-Apr-00	182.28	79204	mL	205.381	ng HCBz on XAD
1131	03-Apr-00	0.00			0.370	ng/mL HCBz in water
1131	03-Apr-00	30.57	433	mL/min	0.303	ng/mL HCBz in water
1131	03-Apr-00	60.77	437	mL/min	0.266	ng/mL HCBz in water
1131	03-Apr-00	91.45	440	mL/min	0.231	ng/mL HCBz in water
1131	03-Apr-00	122.10	446	mL/min	0.179	ng/mL HCBz in water
1131	03-Apr-00	152.63	448	mL/min	0.157	ng/mL HCBz in water
1131	03-Apr-00	183.68	445	mL/min	0.135	ng/mL HCBz in water
1131	03-Apr-00	183.68	81100	mL	124.130	ng HCBz on XAD
1131	10-Apr-00	0.00			0.403	ng/mL HCBz in water
1131	10-Apr-00	30.30	435	mL/min	0.368	ng/mL HCBz in water
1131	10-Apr-00	61.42	437	mL/min	0.316	ng/mL HCBz in water
1131	10-Apr-00	91.22	433	mL/min	0.282	ng/mL HCBz in water
1131	10-Apr-00	121.25	422	mL/min	0.248	ng/mL HCBz in water
1131	10-Apr-00	155.40	424	mL/min	0.220	ng/mL HCBz in water
1131	10-Apr-00	186.23	423	mL/min	0.205	ng/mL HCBz in water
1131	10-Apr-00	186.23	79878	mL	209.444	ng HCBz on XAD

Appendix 4: Batch Sorption Experimental Data

Sorbent concentration (mg/L)	DDT concentration in centrifugate (ng/mL)	HCBz concentration in centrifugate (ng/mL)
0	0.509	0.428
0	0.514	0.437
0	0.531	0.370
226	0.454	0.424
226	0.466	0.383
226	0.472	0.379
453	0.437	0.368
453	0.413	0.368
453	0.457	0.357
679	0.327	0.339
679	0.352	0.368
679	0.370	0.335
1131	0.293	0.339
1131	0.309	0.345
1131	0.278	0.283

Appendix 5: Zooplankton Uptake Experimental Data

DDT						HCBz				
Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)	Water (ng/mL)		Date	Treatment	Total time (hr)	Zoooplankton (ng/g dw)	Water (ng/mL)
14-Jul-99	Clear	2.18	4097	0.377		16-Jul-99	Clear	2.07	4356	0.349
14-Jul-99	Clear	2.18	6304	0.440		16-Jul-99	Clear	2.07	5009	0.375
14-Jul-99	Clear	2.18	8966	0.442		16-Jul-99	Clear	2.07	5023	0.376
14-Jul-99	Clear	4.22	9141	0.329		16-Jul-99	Clear	4.12	7948	0.365
14-Jul-99	Clear	4.22	10816	0.460		16-Jul-99	Clear	4.12	8217	0.368
14-Jul-99	Clear	4.22	12620	0.466		16-Jul-99	Clear	4.12	8857	0.409
14-Jul-99	DOC	2.08	3061	0.458		16-Jul-99	DOC	2.08	3204	0.364
14-Jul-99	DOC	2.08	4163	0.459		16-Jul-99	DOC	2.08	3436	0.385
14-Jul-99	DOC	2.08	4191	0.469		16-Jul-99	DOC	2.08	3589	0.388
14-Jul-99	DOC	4.17	4561	0.407		16-Jul-99	DOC	4.07	4825	0.345
14-Jul-99	DOC	4.17	4629	0.431		16-Jul-99	DOC	4.07	5095	0.353
14-Jul-99	DOC	4.17	7497	0.468		16-Jul-99	DOC	4.07	5724	0.382
14-Jul-99	Glacial high	2.10	4675	0.284		16-Jul-99	Glacial high	2.05	3825	0.347
14-Jul-99	Glacial high	2.10	5795	0.327		16-Jul-99	Glacial high	2.05	4133	0.373
14-Jul-99	Glacial high	2.10	5800	0.338		16-Jul-99	Glacial high	2.05	4291	0.374
14-Jul-99	Glacial high	4.08	9187	0.291		16-Jul-99	Glacial high	4.07	6410	0.359
14-Jul-99	Glacial high	4.08	9418	0.311		16-Jul-99	Glacial high	4.07	6876	0.361
14-Jul-99	Glacial high	4.08	9729	0.372		16-Jul-99	Glacial high	4.07	7123	0.366
14-Jul-99	Glacial low	2.07	5793	0.392		16-Jul-99	Glacial low	2.10	4122	0.324
14-Jul-99	Glacial low	2.07	5849	0.427		16-Jul-99	Glacial low	2.10	4607	0.341
14-Jul-99	Glacial low	2.07	6350	0.460		16-Jul-99	Glacial low	4.07	5860	0.330
14-Jul-99	Glacial low	4.07	9475	0.342		16-Jul-99	Glacial low	4.07	6379	0.330
14-Jul-99	Glacial low	4.07	11911	0.361		16-Jul-99	Glacial low	4.07	7103	0.346
14-Jul-99	Glacial low	4.07	13401	0.382		16-Jul-99	Algae	2.03	1312	0.122
14-Jul-99	Algae	2.08	628	0.255		16-Jul-99	Algae	2.03	1354	0.131
14-Jul-99	Algae	2.08	982	0.268		16-Jul-99	Algae	2.03	1485	0.137
14-Jul-99	Algae	2.08	1219	0.271		16-Jul-99	Algae	4.05	1495	0.112
14-Jul-99	Algae	4.07	1586	0.238		16-Jul-99	Algae	4.05	1628	0.120
14-Jul-99	Algae	4.07	1918	0.262		16-Jul-99	Algae	4.05	1727	0.124
14-Jul-99	Algae	4.07	2691	0.274						

DDT						HCBz				
Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)	Water (ng/mL)		Date	Treatment	Total time (hr)	Zoooplankton (ng/g dw)	Water (ng/mL)
14-Jul-99	Dead	2.03	1074	0.385		16-Jul-99	Dead	2.07	341	0.344
14-Jul-99	Dead	2.03	1189	0.476		16-Jul-99	Dead	2.07	370	0.352
14-Jul-99	Dead	4.02	5094	0.484		16-Jul-99	Dead	2.07	380	0.368
03-Aug-99	Clear	2.02	7518	0.321		16-Jul-99	Dead	4.07	429	0.350
03-Aug-99	Clear	2.02	8675	0.362		16-Jul-99	Dead	4.07	496	0.351
03-Aug-99	Clear	2.02	8885	0.375		16-Jul-99	Dead	4.07	508	0.364
03-Aug-99	Clear	4.05	12456	0.328		02-Aug-99	Clear	2.07	4384	0.082
03-Aug-99	Clear	4.05	12693	0.330		02-Aug-99	Clear	2.07	4629	0.116
03-Aug-99	Clear	4.05	13188	0.362		02-Aug-99	Clear	2.07	4704	0.145
03-Aug-99	Clear	6.00	19834	0.329		02-Aug-99	Clear	4.02	7482	0.053
03-Aug-99	Clear	6.00	20566	0.361		02-Aug-99	Clear	4.02	7874	0.056
03-Aug-99	Clear	6.00	20992	0.380		02-Aug-99	Clear	4.02	8003	0.078
03-Aug-99	DOC	2.00	3399	0.396		02-Aug-99	Clear	6.10	10539	0.048
03-Aug-99	DOC	2.00	4099	0.434		02-Aug-99	Clear	6.10	10454	0.089
03-Aug-99	DOC	2.00	4688	0.448		02-Aug-99	Clear	6.10	10982	0.123
03-Aug-99	DOC	4.05	5323	0.422		02-Aug-99	DOC	2.03	3076	0.079
03-Aug-99	DOC	4.05	5648	0.433		02-Aug-99	DOC	2.03	3133	0.124
03-Aug-99	DOC	4.05	6558	0.438		02-Aug-99	DOC	2.03	3237	0.182
03-Aug-99	DOC	6.05	6922	0.439		02-Aug-99	DOC	4.00	5581	0.116
03-Aug-99	DOC	6.05	7295	0.442		02-Aug-99	DOC	4.00	6057	0.123
03-Aug-99	DOC	6.05	8013	0.456		02-Aug-99	DOC	4.00	6774	0.128
03-Aug-99	Glacial high	2.03	9124	0.289		02-Aug-99	DOC	6.03	7624	0.079
03-Aug-99	Glacial high	2.03	9620	0.303		02-Aug-99	DOC	6.03	7658	0.129
03-Aug-99	Glacial high	2.03	6413	0.320		02-Aug-99	DOC	6.03	7854	0.134
03-Aug-99	Glacial high	3.98	10324	0.258						
03-Aug-99	Glacial high	3.98	11508	0.280						
03-Aug-99	Glacial high	3.98	15132	0.289						
03-Aug-99	Glacial high	6.07	15518	0.248						
03-Aug-99	Glacial high	6.07	15707	0.269						
03-Aug-99	Glacial high	6.07	16639	0.270						

DDT						HCBz				
Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)	Water (ng/mL)		Date	Treatment	Total time (hr)	Zoooplankton (ng/g dw)	Water (ng/mL)
05-Aug-99	Glacial high	2.00	5760	0.366		02-Aug-99	Glacial high	2.03	2843	0.126
05-Aug-99	Glacial high	2.00	5369	0.353		02-Aug-99	Glacial high	2.03	2970	0.130
05-Aug-99	Glacial high	2.00	5281	0.349		02-Aug-99	Glacial high	2.03	3157	0.161
05-Aug-99	Glacial high	4.00	8303	0.317		02-Aug-99	Glacial high	4.02	5187	0.035
05-Aug-99	Glacial high	4.00	8455	0.314		02-Aug-99	Glacial high	4.02	5278	0.113
05-Aug-99	Glacial high	4.00	7409	0.279		02-Aug-99	Glacial high	4.02	5459	0.152
05-Aug-99	Glacial high	5.98	12883	0.311		02-Aug-99	Glacial high	5.98	7454	0.101
05-Aug-99	Glacial high	5.98	13902	0.314		02-Aug-99	Glacial high	5.98	7462	0.103
05-Aug-99	Glacial high	5.98	12998	0.311		02-Aug-99	Glacial high	5.98	7741	0.153
03-Aug-99	Glacial low	2.05	6360	0.332		02-Aug-99	Glacial low	2.02	3798	0.045
03-Aug-99	Glacial low	2.05	6797	0.352		02-Aug-99	Glacial low	2.02	3826	0.064
03-Aug-99	Glacial low	2.05	7218	0.373		02-Aug-99	Glacial low	2.02	3897	0.127
03-Aug-99	Glacial low	4.02	11363	0.323		02-Aug-99	Glacial low	4.02	6157	0.039
03-Aug-99	Glacial low	4.02	11856	0.338		02-Aug-99	Glacial low	4.02	6339	0.073
03-Aug-99	Glacial low	4.02	13188	0.344		02-Aug-99	Glacial low	4.02	6786	0.095
03-Aug-99	Glacial low	5.98	14880	0.301		02-Aug-99	Glacial low	5.98	9730	0.083
03-Aug-99	Glacial low	5.98	16119	0.317		02-Aug-99	Glacial low	5.98	9074	0.088
03-Aug-99	Glacial low	5.98	18125	0.327		02-Aug-99	Glacial low	5.98	9828	0.112
05-Aug-99	Glacial low	2.00	7431	0.399		20-Sep-99	Clear	2.03	398	0.367
05-Aug-99	Glacial low	2.00	7191	0.436		20-Sep-99	Clear	2.03	705	0.356
05-Aug-99	Glacial low	2.00	8102	0.385		20-Sep-99	Clear	2.03	424	0.349
05-Aug-99	Glacial low	4.00	11839	0.395		20-Sep-99	Clear	4.00	795	0.356
05-Aug-99	Glacial low	4.00	12720	0.356		20-Sep-99	Clear	4.00	733	0.322
05-Aug-99	Glacial low	4.00	10234	0.396		20-Sep-99	Clear	4.00	679	0.374
05-Aug-99	Glacial low	5.98	16933	0.390		20-Sep-99	Clear	5.98	746	0.364
05-Aug-99	Glacial low	5.98	16326	0.400		20-Sep-99	Clear	5.98	1039	0.327
05-Aug-99	Glacial low	5.98	18239	0.374		20-Sep-99	Clear	5.98	770	0.341

DDT						HCBz				
Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)	Water (ng/mL)		Date	Treatment	Total time (hr)	Zoooplankton (ng/g dw)	Water (ng/mL)
22-Sep-99	Clear	2.03	7613	0.492		20-Sep-99	DOC	2.02	399	0.371
22-Sep-99	Clear	2.03	8039	0.471		20-Sep-99	DOC	2.02	386	0.355
22-Sep-99	Clear	2.03	7835	0.481		20-Sep-99	DOC	2.02	350	0.324
22-Sep-99	Clear	4.02	10309	0.459		20-Sep-99	DOC	4.03	723	0.357
22-Sep-99	Clear	4.02	11700	0.488		20-Sep-99	DOC	4.03	542	0.324
22-Sep-99	Clear	4.02	10994	0.472		20-Sep-99	DOC	4.03	654	0.326
22-Sep-99	Clear	5.98	13965	0.454		20-Sep-99	DOC	5.98	816	0.328
22-Sep-99	Clear	5.98	16241	0.467		20-Sep-99	DOC	5.98	755	0.333
22-Sep-99	Clear	5.98	16116	0.447		20-Sep-99	DOC	5.98	641	0.362
22-Sep-99	DOC	1.97	6582	0.493		20-Sep-99	Glacial high	2.02	340	0.294
22-Sep-99	DOC	1.97	5972	0.463		20-Sep-99	Glacial high	2.02	295	0.317
22-Sep-99	DOC	1.97	5391	0.487		20-Sep-99	Glacial high	2.02	285	0.326
22-Sep-99	DOC	3.98	7355	0.503		20-Sep-99	Glacial high	4.03	477	0.313
22-Sep-99	DOC	3.98	5770	0.480		20-Sep-99	Glacial high	4.03	670	0.306
22-Sep-99	DOC	3.98	5634	0.498		20-Sep-99	Glacial high	4.03	1018	0.319
22-Sep-99	DOC	6.00	8656	0.448		20-Sep-99	Glacial high	5.98	791	0.327
22-Sep-99	DOC	6.00	8998	0.481		20-Sep-99	Glacial high	5.98	803	0.298
22-Sep-99	DOC	6.00	7044	0.471		20-Sep-99	Glacial high	5.98	730	0.296
22-Sep-99	Glacial high	2.03	4787	0.336		20-Sep-99	Glacial low	2.05	324	0.322
22-Sep-99	Glacial high	2.03	4508	0.373		20-Sep-99	Glacial low	2.05	408	0.361
22-Sep-99	Glacial high	2.03	4120	0.373		20-Sep-99	Glacial low	2.05	432	0.355
22-Sep-99	Glacial high	4.00	5938	0.335		20-Sep-99	Glacial low	4.02	814	0.327
22-Sep-99	Glacial high	4.00	5946	0.334		20-Sep-99	Glacial low	4.02	565	0.360
22-Sep-99	Glacial high	4.00	6766	0.343		20-Sep-99	Glacial low	4.02	561	0.360
22-Sep-99	Glacial high	6.02	9944	0.349		20-Sep-99	Glacial low	5.98	697	0.336
22-Sep-99	Glacial high	6.02	9445	0.346		20-Sep-99	Glacial low	5.98	865	0.336
22-Sep-99	Glacial high	6.02	8777	0.335		20-Sep-99	Glacial low	5.98	818	0.365
22-Sep-99	Glacial low	2.03	6508	0.480						
22-Sep-99	Glacial low	2.03	7299	0.404						
22-Sep-99	Glacial low	2.03	6685	0.398						
22-Sep-99	Glacial low	4.02	10194	0.425						
22-Sep-99	Glacial low	4.02	10107	0.451						

DDT						HCBz				
Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)	Water (ng/mL)		Date	Treatment	Total time (hr)	Zoooplankton (ng/g dw)	Water (ng/mL)
22-Sep-99	Glacial low	4.02	11174	0.449		20-Sep-99	Algae	2.03	65	0.083
22-Sep-99	Glacial low	5.97	15169	0.460		20-Sep-99	Algae	2.03	135	0.081
22-Sep-99	Glacial low	5.97	14249	0.475		20-Sep-99	Algae	2.03	109	0.097
22-Sep-99	Glacial low	5.97	16505	0.463		20-Sep-99	Algae	4.05	136	0.061
22-Sep-99	Algae	2.05	536	0.198		20-Sep-99	Algae	4.05	129	0.062
22-Sep-99	Algae	2.05	605	0.204		20-Sep-99	Algae	4.05	171	0.070
22-Sep-99	Algae	2.05	378	0.224		20-Sep-99	Algae	6.02	79	0.049
22-Sep-99	Algae	4.00	596	0.188		20-Sep-99	Algae	6.02	123	0.065
22-Sep-99	Algae	4.00	613	0.175		20-Sep-99	Algae	6.02	90	0.057
22-Sep-99	Algae	4.00	654	0.176						
22-Sep-99	Algae	6.00	494	0.185						
22-Sep-99	Algae	6.00	566	0.184						
22-Sep-99	Algae	6.00	952	0.152						

Appendix 6: Zooplankton Elimination Experimental Data

DDT					HCBz			
Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)		Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)
21-Jul-99	t=0	0	14086		21-Jul-99	t=0	0	7970
21-Jul-99	t=0	0	15705		21-Jul-99	t=0	0	8992
21-Jul-99	t=0	0	13739		21-Jul-99	t=0	0	10629
21-Jul-99	Clear	24	9303		21-Jul-99	Clear	24	3617
21-Jul-99	Clear	24	10898		21-Jul-99	Clear	24	4333
21-Jul-99	Clear	24	7492		21-Jul-99	Clear	24	3608
21-Jul-99	Clear	48	8961		21-Jul-99	Clear	48	438
21-Jul-99	Clear	48	6522		21-Jul-99	Clear	48	1097
21-Jul-99	Glacial high	24	9356		21-Jul-99	Glacial high	24	2661
21-Jul-99	Glacial high	24	9964		21-Jul-99	Glacial high	24	4654
21-Jul-99	Glacial high	24	9220		21-Jul-99	Glacial high	24	2040
21-Jul-99	Glacial high	48	8458		21-Jul-99	Glacial high	48	1096
21-Jul-99	Glacial high	48	8918		21-Jul-99	Glacial high	48	1161
21-Jul-99	Glacial low	24	9880		21-Jul-99	Glacial high	48	1232
21-Jul-99	Glacial low	24	10298		21-Jul-99	Glacial low	24	4260
21-Jul-99	Glacial low	24	5162		21-Jul-99	Glacial low	24	4341
21-Jul-99	Glacial low	48	9363		21-Jul-99	Glacial low	24	3656
21-Jul-99	Glacial low	48	8691		21-Jul-99	Glacial low	48	700
21-Jul-99	Glacial low	48	9105		21-Jul-99	Glacial low	48	1987
21-Jul-99	Algae	24	10033		21-Jul-99	Glacial low	48	1328
21-Jul-99	Algae	24	8080		21-Jul-99	Algae	24	3956
21-Jul-99	Algae	24	9551		21-Jul-99	Algae	24	2388
21-Jul-99	Algae	48	7775		21-Jul-99	Algae	24	2609
21-Jul-99	Algae	48	7524		21-Jul-99	Algae	48	1232
21-Jul-99	Algae	48	7919		21-Jul-99	Algae	48	1578
05-Aug-99	t=0	0	16934		21-Jul-99	Algae	48	1130
05-Aug-99	t=0	0	15535		05-Aug-99	t=0	0	9006
05-Aug-99	t=0	0	18372		05-Aug-99	t=0	0	9483
05-Aug-99	Clear	24	11236		05-Aug-99	t=0	0	10170
05-Aug-99	Clear	24	11107		05-Aug-99	Clear	12	7148
05-Aug-99	Clear	24	9708		05-Aug-99	Clear	12	7472
05-Aug-99	Clear	48	11561		05-Aug-99	Clear	12	6813

DDT					HCBz			
Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)		Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)
05-Aug-99	Clear	48	10532		05-Aug-99	Clear	24	5155
05-Aug-99	Clear	48	12190		05-Aug-99	Clear	24	5082
05-Aug-99	Clear	72	10096		05-Aug-99	Clear	24	5947
05-Aug-99	Clear	72	10048		05-Aug-99	Clear	48	4129
05-Aug-99	Clear	72	10432		05-Aug-99	Clear	48	3905
05-Aug-99	Glacial high	24	10839		05-Aug-99	Clear	48	3822
05-Aug-99	Glacial high	24	11332		05-Aug-99	Glacial high	12	7327
05-Aug-99	Glacial high	24	11139		05-Aug-99	Glacial high	12	6751
05-Aug-99	Glacial high	48	11656		05-Aug-99	Glacial high	12	7260
05-Aug-99	Glacial high	48	10001		05-Aug-99	Glacial high	24	5850
05-Aug-99	Glacial high	48	11141		05-Aug-99	Glacial high	24	6228
05-Aug-99	Glacial high	72	10154		05-Aug-99	Glacial high	24	6917
05-Aug-99	Glacial high	72	10359		05-Aug-99	Glacial high	48	4579
05-Aug-99	Glacial high	72	9861		05-Aug-99	Glacial high	48	4448
05-Aug-99	Glacial low	24	11562		05-Aug-99	Glacial high	48	5124
05-Aug-99	Glacial low	24	11285		05-Aug-99	Glacial low	12	6939
05-Aug-99	Glacial low	24	10980		05-Aug-99	Glacial low	12	7382
05-Aug-99	Glacial low	48	10205		05-Aug-99	Glacial low	12	7490
05-Aug-99	Glacial low	48	9699		05-Aug-99	Glacial low	24	5270
05-Aug-99	Glacial low	48	11004		05-Aug-99	Glacial low	24	5622
05-Aug-99	Glacial low	72	9232		05-Aug-99	Glacial low	24	5806
05-Aug-99	Glacial low	72	9827		05-Aug-99	Glacial low	48	3559
05-Aug-99	Glacial low	72	8573		05-Aug-99	Glacial low	48	3641
21-Sep-99	t=0	0	15446		05-Aug-99	Glacial low	48	3275
21-Sep-99	t=1	0	12953		21-Sep-99	t=0	0	6559
21-Sep-99	t=2	0	13577		21-Sep-99	t=0	0	6236
21-Sep-99	Clear	24	9151		21-Sep-99	t=0	0	6755
21-Sep-99	Clear	24	9609		21-Sep-99	Clear	12	4228
21-Sep-99	Clear	24	9649		21-Sep-99	Clear	12	3892
21-Sep-99	Clear	48	10426		21-Sep-99	Clear	12	3596
21-Sep-99	Clear	48	9920		21-Sep-99	Clear	24	2034
21-Sep-99	Clear	48	9751		21-Sep-99	Clear	24	3219

DDT					HCBz			
Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)		Date	Treatment	Total time (hr)	Zooplankton (ng/g dw)
21-Sep-99	Clear	72	8290		21-Sep-99	Clear	24	3678
21-Sep-99	Clear	72	8037		21-Sep-99	Clear	48	966
21-Sep-99	Clear	72	8712		21-Sep-99	Clear	48	942
21-Sep-99	Glacial high	24	10250		21-Sep-99	Clear	48	1631
21-Sep-99	Glacial high	24	10297		21-Sep-99	Glacial high	12	3640
21-Sep-99	Glacial high	24	10865		21-Sep-99	Glacial high	12	4048
21-Sep-99	Glacial high	48	8150		21-Sep-99	Glacial high	12	3411
21-Sep-99	Glacial high	48	9458		21-Sep-99	Glacial high	24	2294
21-Sep-99	Glacial high	48	9903		21-Sep-99	Glacial high	24	2986
21-Sep-99	Glacial high	72	8875		21-Sep-99	Glacial high	24	2631
21-Sep-99	Glacial high	72	7871		21-Sep-99	Glacial high	48	1122
21-Sep-99	Glacial high	72	8563		21-Sep-99	Glacial high	48	978
21-Sep-99	Glacial low	24	9958		21-Sep-99	Glacial high	48	1637
21-Sep-99	Glacial low	24	10102		21-Sep-99	Glacial low	12	3451
21-Sep-99	Glacial low	24	9514		21-Sep-99	Glacial low	12	3076
21-Sep-99	Glacial low	48	8936		21-Sep-99	Glacial low	12	4042
21-Sep-99	Glacial low	48	8793		21-Sep-99	Glacial low	24	2111
21-Sep-99	Glacial low	48	8474		21-Sep-99	Glacial low	24	2668
21-Sep-99	Glacial low	72	7561		21-Sep-99	Glacial low	24	2554
21-Sep-99	Glacial low	72	7478		21-Sep-99	Glacial low	48	1592
					21-Sep-99	Glacial low	48	736
					21-Sep-99	Glacial low	48	2175